MAYO AERO MEDICAL UNIT

STUDIES IN AVIATION MEDICINE

Volume VI

Final Report
Summary and Bibliography

MAYO AERO MEDICAL UNIT

<u>STUDIES IN AVIATION MEDICINE</u>

Carried out with the assistance of the

NATIONAL RESEARCH COUNCIL, DIVISION OF MEDICAL SCIENCES

acting for the

COMMITTEE ON MEDICAL RESEARCH

of the

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

With the cooperation of the

UNITED STATES ARMY AIR FORCES, MATERIEL COMMAND, WRIGHT FIELD

Responsible Investigators: Walter M. Boothby, E. J. Baldes and C. F. Code

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These reports, originally in "confidential" classification, have been declassified and all are now "open."

VOLUME [illegible] FINAL REPORT

Mayo Clinic and Mayo Foundation for
Medical Education and Research
University of Minnesota

Rochester, Minnesota
[illegible]

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aided by many associates.

In Six Volumes

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VOLUME 6: FINAL REPORT

Mayo Clinic and Mayo Foundation for
Medical Education and Research,
University of Minnesota

Rochester, Minnesota
1940 - 1945

COMMITTEE ON WAR MEDICINE, MAYO ASSOCIATES
representing the
MAYO CLINIC AND MAYO FOUNDATION FOR MEDICAL EDUCATION AND RESEARCH
Dr. D.C. Balfour, Dr. C.W. Mayo*, Dr. R.D. Mussey, Dr. A.R. Barnes and Mr. H.J. Harwick

STAFF OF THE MAYO AERO MEDICAL UNIT

Responsible Investigators

High Altitude Laboratory: Walter M. Boothby, Chairman. Member of the Subcommittee on Oxygen and Anoxia of the Committee on Aviation Medicine, National Research Council.

Acceleration Laboratory:** E.J. Baldes, Vice Chairman. Member of the Subcommittee on Acceleration of the Committee on Aviation Medicine, National Research Council.
C.F. Code, Secretary. Member of the Subcommittee on Decompression Sickness of the Committee on Aviation Medicine, National Research Council.

Investigators

Staff of the Mayo Clinic and Mayo Foundation: (Full time) E.J. Baldes, J.B. Bateman, W.M. Boothby, A.H. Bulbulian, C.F. Code, H.F. Helmholz, Jr., E.H. Lambert, W.R. Lovelace, II and E.H. Wood. (Part time) J.D. Akerman,*** J. Berkson, H.B. Burchell, P.L. Cusick, H.E. Essex, G.A. Hallenbeck, W.W. Heyerdale, H.C. Hinshaw, J. Piccard,*** M.H. Power, C. Sheard, J.H. Tillisch, M.N. Walsh and M.M.D. Williams.

Fellows of the Mayo Foundation: R. Bratt, B.P. Cunningham, W.H. Dearing, E.W. Erickson, N.E. Erickson, J.H. Flinn, J.K. Keeley, J. Pratt, F.J. Robinson, R.F. Rushmer, G.F. Schmidt, H.C. Shands, H.A. Smedal, A.R. Sweeney, A. Uihlein, R. Wilder, Jr., J. Wilson and K.G. Wilson.

Officer assigned by the Air Transport Command of the Army Air Forces: K.R. Bailey, pilot.

Officers assigned by Air Surgeon's Office: O.O. Benson, Jr., J.W. Brown, J.H. Bundy, D. Coats, E. Eagle, M.F. Green, J.R. Halbouty, R.B. Harding, J.P. Marbarger, M.M. Guest, O.C. Olson, C.M. Osborne, H. Parrack, N. Rakieten, J.A. Resch, H.A. Robinson, H.E. Savely, C.B. Taylor, L. Toth and J.W. Wilson.

Officers assigned by the Navy: W. Davidson and D.W. Gressley.

Officers sent by other governments: J.R. Delucchi, Argentina, and R.T. Prieto, Mexico.

Other investigators: M. Burcham, C.J. Clark, M.A. Crispin, R.E. Jones, G. Knowlton, H. Lamport, C.A. Lindbergh, C.A. Maaske, G.L. Maison, A. Reed and R.E. Sturm.

Technicians

High Altitude Laboratory: Henrietta Cranston, Lucille Cronin, Ruth Knutson, Eleanor Larson and Rita Schmelzer; Margaret Jackson (from Wright Field).

Acceleration Laboratory: L. Coffey, R. Engstrom, H. Haglund and A. Porter; Ruth Bingham, Velma Chapman, Marjorie Clark, Wanda Hampel and Marguerite Koelsch.

Secretaries

Evelyn Cassidy, Esther Fyrand, Marian Jenkins and Ethel Leitzen.

* Before going into military service.

** The major reports of the Acceleration Laboratory will be published shortly in the monograph entitled "The Effects of Acceleration and Their Amelioration," edited by the Subcommittee on Acceleration of the Committee on Aviation Medicine of the National Research Council.

*** From the Department of Aeronautical Engineering, University of Minnesota.

NATIONAL RESEARCH COUNCIL, DIVISION OF MEDICAL SCIENCES

acting for the

COMMITTEE ON MEDICAL RESEARCH
of the
Office of Scientific Research and Development

COMMITTEE ON AVIATION MEDICINE

OEMcmr-129

OPEN

Final Report
June 15, 1946

THE MAYO AERO MEDICAL UNIT, ROCHESTER, MINNESOTA: FINAL REPORT INCLUDING A BRIEF HISTORY, SOME OF THE MORE IMPORTANT CHARTS CONTAINING DATA, AND COMPLETE BIBLIOGRAPHY FOR BOTH THE HIGH ALTITUDE AND ACCELERATION LABORATORIES.

Responsible Investigators:

W. M. Boothby, M.D., E. J. Baldes, Ph.D. and C. F. Code, M.D.

SUMMARY

The final report of the Mayo Aero Medical Unit includes a list of our co-workers, a brief history of the development of the Unit and a very short account of the chief problems investigated.

Charts illustrating the more important physiologic data contained in our various reports have been arranged in eight subject groups to present a fairly comprehensive summary of the research carried out in the High Altitude Laboratory. The data of the Acceleration Laboratory is being presented later in a monograph form.

Complete bibliography of both the High Altitude and Acceleration Laboratories is attached.

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Responsible Investigators of the Mayo Aero Medical Unit:

High Altitude Laboratory:

Walter M. Boothby, Chairman. Member of the Subcommittee on Oxygen and Anoxia of the Committee on Aviation Medicine, National Research Council.

Acceleration Laboratory:

E. J. Baldes, Vice-Chairman. Member of the Subcommittee on Acceleration of the Committee on Aviation Medicine, National Research Council.

C. F. Code, Secretary. Member of the Subcommittee on Decompression Sickness of the Committee on Aviation Medicine, National Research Council.

Investigators:

(A) Full time staff for 1 year or more: E. J. Baldes, J. B. Bateman, W. M. Boothby, A. H. Bulbulian, C. F. Code, H. F. Helmholz, Jr., E. H. Lambert, W. R. Lovelace, II, R. E. Sturm and E. H. Wood.

(B) Part time: J. D. Akerman, J. Berkson, H. B. Burchell, P. L. Cusick, G. A. Hallenbeck, W. W. Heyerdale, H. C. Hinshaw, R. E. Jones, J. Piccard, M. H. Power, C. Sheard, J. H. Tillisch, M. N. Walsh and M. M. D. Williams.

Officer assigned by Air Transport Command of the Army Air Forces for acceleration studies: K. R. Bailey, pilot.

Officers sent by Air Surgeon's Office for periods of 1 month to 1 year: O. O. Benson, Jr., J. W. Brown, E. Eagle, M. F. Green, J. R. Halbouty, J. P. Marbarger, M. M. Guest, O. C. Olson, C. M. Osborne, H. Parrack, N. Rakieten, J. A. Resch, H. A. Robinson, C. B. Taylor and L. Toth; also J. W. Wilson from Wright Field for joint acclimatization investigation at Colorado Springs.

Officers sent by the Navy who were assigned for an appreciable length of time: W. Davidson and D. W. Gressley.

Officers sent by other governments: J. R. Delucchi, Argentina, and R. T. Prieto, Mexico.

Other investigators who did actual work: M. Burcham, C. J. Clark, M. A. Crispin, C a Maasche
G Knowlton, H. Lamport, C. A. Lindbergh and Dr. Maison.

Assistant investigators: R. Bratt, B. P. Cunningham, N. E. Erickson, J. H. Flinn, J. K. Keeley, J. Pratt, F. J. Robinson, R. F. Rushmer, G. F. Schmidt, H. C. Shands, H. A. Smedal, A. R. Sweeney, A. Uihlein, R. Wilder, Jr., J. Wilson and K. G. Wilson.

High Altitude Laboratory technicians: Henrietta Cranston, Lucille Cronin, Ruth Knutson, Eleanor Larson and Rita Schmelzer; Margaret Jackson (from Wright Field).

Acceleration Laboratory technicians: L. Coffey, R. Engstrom, H. Haglund and A. Porter; Ruth Bingham, Velma Chapman, Marjorie Clark, Wanda Hampel and Marguerite Keelsch.

Secretaries: Evelyn Cassidy, Esther Fyrand, Marian Jenkins and Ethel Leitzen.

Visitors: Our guest book contains the names of many noted Air Forces personnel and civilian investigators from our own country and from our Allies. As some came on what at the time were confidential missions, it is best not to include any list, although each one contributed many very important and valuable suggestions which helped greatly.

The responsible investigators realize that any important or valuable results either scientific or military that have emanated from the Mayo Aero Medical Unit are due to complete whole-hearted cooperation on the part of all who were in any way connected with the Mayo Aero Medical Unit. This cooperation was extended to and reciprocated by all the governmental agencies, civilian and military, concerned with our efforts as well as with the staff of all the industrial groups who perfected our laboratory models to meet the needs of large scale production for the Army and Navy Air Forces. Of necessity our work was largely applied research and not an attempt to advance pure science nor to obtain data for World War III. The atomic scientists had an unparalleled opportunity to "mass investigate" the fundamental relationship between mass and energy because of the tremendous power attainable if release was successful. Not so in aviation medicine - our duty (at least so it seemed to us) was immediately to use the scientific facts already known, or should we say select the best established facts and theories and then retest and measure their applicability and efficiency, in the construction of practicable apparatus and procedures to increase the safety of both civilian and military aviators.

The serious effect of anoxia on the human organism in sickness and in health has been long recognized. Its importance in military medicine and in aviation was investigated and emphasized especially by Haldane in World War I. Studies on anoxia and methods of oxygen administration have been carried out in the Metabolism Laboratory of the Mayo Clinic and Foundation since 1918 by Dr. Boothby. The oxygen chambers installed in 1925 for clinical therapy proved very useful in the early studies in aviation medicine and were used frequently by the addition of nitrogen to simulate altitude during 1938 and early 1939. As a result of this work the Board of Governors of the Mayo Clinic and Foundation, represented by Dr. C. W. Mayo, decided to expand the facilities and increase the personnel available for research

in the broad aspects of aviation medicine. Early in 1939 the first low pressure chamber in a civilian laboratory in the United States was installed and studies on high altitude physiology were intensified after the full-time assignment of Dr. W. R. Lovelace, II, to the laboratory by the Mayo Foundation.

Simultaneously early in 1939 Dr. A. H. Bulbulian, in conjunction with Dr. Lovelace and Dr. Boothby, started to develop oxygen masks (B.L.B.) suitable for use both in clinical medicine and in aviation. At that time no accurate data were available on how much oxygen was needed out of a cylinder to maintain an aviator in normal condition or to what altitudes an aviator could go and still function normally. Therefore, studies not only on oxygen equipment but on the rates of flow needed at increasing altitudes had first to be carried out, theoretically, on the basis of a constant tracheal oxygen pressure for a respiratory volume of 10 liters (B.T.P.S.) per minute at rest and for moderate work at a respiratory volume of 20 and of 30 liters per minute and, second, to confirm such calculations by actual determination of the alveolar CO_2 and O_2 pressures at increasing altitudes.

In conjunction with Dr. J. A. Heidbrink, the constant flow kinetic type of flow meter was calibrated in a specially designed glass bell jar that could be easily evacuated to desired pressure altitude for the appropriate flows of oxygen per minute (S.T.P.D.) needed to maintain aviators normal at rest and at work.

By the middle of 1939 the administration of oxygen by means of the B.L.B. oxygen mask was being used extensively for oxygen therapy at the Mayo Clinic.

The various clinical conditions which were found to be helped by the use of high concentration of oxygen were rapidly widening. In the practical application and in a better understanding of the underlying physiological mechanism of oxygen therapy we were greatly aided by the visit of the noted British scientists, Dr. Henry Tidy, Dr. J. Forest Smith and Prof. B. A. McSwiney, all from St. Thomas Hospital, London. Great Britain at that time was fearful of massive poison gas attacks on the civilian population from German airplanes should war develop, and the scientists were sent by the Royal Society to determine with utmost speed the practicability of clinical administration of high oxygen concentration. They and our entire laboratory staff worked intensively on many problems of oxygen therapy and in making comparative tests of the various methods for administration. In conjunction with Prof. McSwiney a series of alveolar air determinations were obtained when using various modifications of masks and other types of apparatus on three subjects, small, medium and large, at increasing rates of oxygen flow from 1 to 10 liters per minute.

The methods of technic used in these experiments were primarily planned for studying clinical oxygen therapy at ground level. However, the same methods were immediately found applicable in studying the effects of oxygen administration, both by a constant flow reservoir rebreathing mask and by the demand type mask, to subjects at simulated high altitude in low pressure chambers. Thus was perfected a routine method by which the efficiency of various types of oxygen administration could be positively and accurately determined on aviators. As a result it was possible to establish not only the optimum oxygen requirement needed by aviators for all altitudes but also the minimum specification permissible. It was found that so far as anoxia was concerned, the desirable specification was the maintenance of the same concentration of oxygen in the "tracheal" air as exists at or near sea level where

$$\text{Tracheal } pO_2 = (B-47)\ 0.21.$$

A definite educational program was instituted so that aviators - flyers and manufacturers - would become acquainted with the desirability of the use of oxygen at altitudes in excess of 10,000 or 12,000 feet, and its absolute necessity for altitudes in excess of 15,000 feet if the aviators were to remain there for more than a few minutes.

Several commercial airlines shortly began to install the new types of equipment as they became available for the administration of oxygen, not only for the pilot and co-pilot but also in some instances for passengers.

Simultaneously studies were initiated at the Mayo Aero Medical Unit on how to protect aviators from developing bends such as were known to be common to divers upon ascending from considerable depths of water. Many experiments were carried out to determine the rate at which the body nitrogen could be eliminated at rest and at work. The experimental data when plotted (see attached chart) on semi-logarithmic paper showed curves both for the experiment at rest and at work which suggested an asymptote around 1200 to 1500 cc. However, when plotted on log-log paper the individual experiment showed that the data representing accumulated nitrogen elimination fell on perfectly straight lines within the limits of 120 minutes. This log-log plot was very convenient because it could of course be directly transformed into a straight line indicating rate of elimination in cubic centimeters per minute. In one experiment the rate of elimination when extrapolated passed very close to the rate of elimination directly determined on another day on the same subject after breathing oxygen for eight hours.

The straight lines and their change in slope at rest and at work indicates that at least two major factors control the rate of nitrogen elimination: (1) the concentration of nitrogen in the body tissues and (2) the rate of circulation of the blood stream. These important points were not at the time investigated in greater detail as to do so new apparatus had to be constructed.

The beneficial effect of denitrogenation by breathing oxygen with and without exercise was established in the laboratory in 1939 as a practical method of preventing the bends. The value of denitrogenation in actual flight at high altitude was studied in conjunction with the Experimental Flight Department of the Boeing Aircraft Company. The results of these studies, at that time "confidential," were presented in a statistical report by Engineering Test Pilot Marvin Michael and by Dr. W. E. Russell to a closed session of the Aero Medical Association at Indianapolis, Indiana in September 1942. A photograph showing the method then in use as preliminary to flights between 30,000 and 40,000 feet appeared in Boeing News, Vol. XI, No. 5, May 1941.

These various investigations so briefly enumerated here also attracted the attention of other aircraft manufacturers who were designing new high altitude aircraft and of the test pilots who expected soon to be testing such airplanes; the latter appreciated efforts to reduce the hazard of their tests.

Visits by these test pilots to the laboratory for indoctrination increased by their timely and pertinent suggestions the ability of the rapidly growing group of investigators at the Mayo Aero Medical Unit to direct their advice and research along practical lines for the safety of pilots at high altitudes. From them we learned what procedures were possible for them to use and to recognize quickly what methods, although able to be carried out in the laboratory, were utterly impossible to do in

the type of airplane they were flying. The design engineers soon began to learn that they must provide space for oxygen cylinders and other safety equipment. An interesting observation was made by us, namely, the design engineers of bombers or multiple seat airplanes learned more quickly the necessity for safety of the pilot because in these planes the engineers themselves had to share the dangers of the test flights. Today one can hardly think back and realize the efforts needed to overcome the prejudices of World War I pilots, especially if they had become high executives, who believed that military airplanes need not be provided with safety devices, and that "comfort" would "soften" a fighter.

In view of the general interst in increasing the safety of civil aviation and the growing concern of the Army and Navy Air Forces over the military significance of high altitude flying, close cooperation on an informal basis was established with Colonel (later General) D. N. W. Grant, the Air Surgeon, with Captain (later Colonel) H. G. Armstrong, Chief of the Aero Medical Laboratory at Wright Field, with Captain (later Commodore) J. C. Adams, Bureau of Medicine and Surgery, Division of Aviation Medicine, U.S.N., and with the Assistant Secretary R. H. Hinckley of the Department of Commerce in charge of civil aviation. American aviators were fortunate indeed to have such able and far-seeing men in charge of providing and continually improving on a large scale safety apparatus not only for civilian but also for military aviators.

In 1939 and 1940 Colonel Grant assigned to the Mayo Aero Medical Unit for instruction and to conduct investigations Captains O. O. Benson, Jr., J. A. Resch, J. R. Halbouty and J. W. Brown, and from the Mayo Foundation were assigned for full time work Doctors H. F. Holmholz, Jr., J. K. Keeley, J. Pratt, R. F. Rushmer, G. F. Schmidt, H. A. Smedal, A. Uihlein and J. W. Wilson; in addition many others voluntarily worked part time in the laboratory of whom we mention only Dr. W. W. Heyerdale. Professor Akerman arranged for Mr. N. E. Erickson and Mr. R. Bratt, advanced students in the Department of Aeronautical Engineering at the University of Minnesota, to each spend a year in the laboratory. Many of these investigators, when war against the United States broke out, went into military or civilian service where their early training in aviation medicine led to important assignments. Captain (later Colonel) Benson became Chief of the Aero Medical Laboratory at Wright Field and later Air Surgeon for the Mediterranean Theater. Dr. Lovelace entered the Army and as Major was assigned to the Office of the Air Surgeon and later as Colonel became Chief of the Aero Medical Laboratory at Wright Field. Dr. Smedal became Flight Surgeon on an aircraft carrier and later, as Commander, was in charge of the High Altitude Laboratory at Pensacola. Dr. Keeley early entered the Army, was sent to the Philippines and became a prisoner of war; upon release he returned to the Mayo Clinic fortunately in good health. Dr. Heyerdale entered service and was sent to the South West Pacific Theater - he was killed on active duty in New Caledonia. Dr. Rushmer, shortly after entering service, was assigned to the Research Laboratory of the School of Aviation Medicine, Randolph Field. Dr. Helmholz, Jr., inaugurated and became Chief of the High Altitude Laboratory, Flight Research Department of Consolidated Vultee Aircraft Corporation at San Diego; he also continued as Research Associate at the Mayo Aero Medical Unit and by alternating monthly between the two positions created a mutually beneficial and effective liaison.

During this early period many papers were presented at medical meetings and were published in medical journals on anoxia and oxygen administration. A mimeographed list of the papers by the staff, including titles and references are, for the convenience of readers, attached as an Appendix to this report. Copies can

be obtained on request, and those papers primarily concerned with aviation can be found under the name of the author in "A Bibliography of Aviation Medicine" compiled by E. C. Hoff and J. F. Fulton for the Committee on Aviation Medicine, National Research Council.

These early pre-war studies on high altitude physiology attracted much attention as evidenced by visits from Major (later Lt. General) Doolittle, Major Lester Gardner, Miss Jacqueline Cochran and by the award at the White House of the Collier Trophy for 1939 by President Roosevelt to Drs. Walter M. Boothby and W. Randolph Lovelace, II, of the Mayo Foundation and to Capt. Harry G. Armstrong, M.C., U.S.A., currently Chief of the Aero Medical Laboratory at Wright Field.

The studies and papers mentioned rendered possible and formed the basis for the high altitude studies in physiology and oxygen equipment continued at the Mayo Aero Medical Unit under the auspices of the Committee on Aviation Medicine, Division of Medical Sciences, National Research Council, acting for the Committee on Medical Research, Office of Scientific Research and Development, Washington, D. C.

Studies on acceleration were initiated early in 1941 by the design and construction at the Institute of Experimental Medicine of a pilot model centrifuge by Dr. E. J. Baldes assisted by Mr. Adrien Porter. Various physiological studies, mostly on animals, were carried out by Dr. C. F. Code, Dr. G. A. Hallenbeck and Capt. J. A. Resch, M.C., U.S.A.; also on this centrifuge the first moving pictures of blackout and unconsciousness of a human being were obtained in the fall of 1941 on Capt. Resch, who volunteered as a subject: it was a striking picture of rapid development of old age, apparent death and complete rapid restoration.

The data obtained on this pilot model demonstrated the importance of carrying out extensive studies on acceleration, and the Mayo Properties Association authorized Dr. Baldes to design and construct a large human centrifuge. In the design and construction, Dr. Baldes received helpful suggestions from the engineers of the Sperry Gyroscope Company, and also of the Timken Roller Bearing Company. The superstructure of this centrifuge has an 18-foot radius. It is completely equipped with electronic and other types of recording instruments and is installed in a specially designed circular room of reinforced concrete with an elevated "control tower."

After the human centrifuge and its equipment became available, Dr. Code and Dr. Baldes, aided by Drs. G. A. Hallenbeck, E. H. Lambert, E. H. Wood, Mr. R. E. Sturm (electronic engineer) and Mr. L. Coffey (photographer), planned and devised a great variety of methods to study the effects of centrifugal force upon various measurable physiologic mechanisms. Dr. Code also emphasized the necessity and importance of objective methods for the bio-assay analysis of protective equipment. Many Army and Navy Air Force and medical officers and test pilots cooperated in various specific problems of special military interest.

The centrifuge, its electronic and other recording apparatus, a large low pressure chamber equipped with all types of oxygen apparatus, and a small low pressure chamber with refrigeration facilities to -70° F., and necessary respiratory, blood gas and accessory apparatus were installed in a new specially designed laboratory building in the spring of 1942. The equipment and the staff to man it were contributed and maintained by the Mayo Properties Association on behalf of the Mayo

Clinic and Mayo Foundation for Medical Education and Research as part of their war effort. In 1944 they also authorized the construction of a vertical centrifuge to aid in solving certain special problems of immediate importance on a new type pursuit aircraft - the P-82.

The Mayo Aero Medical Unit at the time of Pearl Harbor was thus ready both with apparatus and trained personnel immediately to play its part in the intensive research work in aviation medicine then being inaugurated in the various civilian laboratories under the auspices of the Office of Scientific Research and Development and simultaneously to continue the cooperative research already under way with the Army and Navy Air Forces.

On January 21, 1942 the Mayo Aero Medical Unit was visited by the Committee on Aviation Medicine of the National Research Council together with several liaison officers. The following were present: Prof. H. C. Bazett, Banting Institute, University of Toronto, Toronto, Canada; E. M. Landis, Professor of Medicine, University of Virginia; L. E. Griffis, Lt. Col., Air Surgeon's Office, Washington, D. C.; Eric Liljencrantz, Comdr., U.S.N.R., Bureau of Medicine and Surgery, Navy Department, Washington, D. C.; E. C. Andrus, Technical Aide, Department of Medicine, Johns Hopkins University; T. C. MacDonald, Wing Commander, R.A.F., Air Ministry, London; C. F. Schmidt, Prof. of Pharmacology, University of Pennsylvania; D. W. Bronk, Director, Johnson Foundation, University of Pennsylvania; W. R. Miles, Prof. of Psychology, Yale University School of Medicine, E. F. DuBois, Prof. of Medicine, Cornell Medical School; J. F. Fulton, Prof. of Physiology, Yale University School of Medicine.

Shortly after this visit the activities of the Mayo Aero Medical Unit were formalized and the financial support by the Mayo Properties Association continued under their Committee on War Medicine consisting of Dr. D. C. Balfour, Dr. R. D. Mussey, Dr. A. R. Barnes and Mr. H. J. Harwick representing the Mayo Clinic and Mayo Foundation for Medical Education and Research. This Committee completed formal contracts with the officials of the Army Air Forces Materiel Command (Aero Medical Laboratory) at Wright Field and with the Office of Emergency Management through the Committee on Medical Research, National Research Council as follows:

I. Contract No. W535-ac-25829 (issued 6 February 1942, signed 11 March 1942), Contract No. AC-25829 (1943) and Contract No. W(33-038)ac-9166 (1945) with the Army Air Forces Materiel Command.

II. Contract No. OEMcmr-129 with the Committee on Medical Research of the Office of Scientific Research and Development, 20 March 1942.

During the investigations, however, there was no attempt made to separate the studies made under these two contracts or that continued informally with the Navy or with various aircraft manufacturers. Nor could the early work under these contracts be separated from the basic studies briefly described above as carried out between 1939 and 1942, some of which had already been published. The studies after 1942 which were directly requested by the Armed Forces have been placed in the attached bibliography of our classified materials as AAF-CMR reports. Other studies were sent in for publication as CAM reports and are listed by the CAM number assigned by that office. Because the three Responsible Investigators were each a member of a separate Subcommittee some formal and informal reports were made directly to the Subcommittee on Oxygen and Anoxia, to the Subcommittee on Acceleration, or to the

Subcommittee on Decompression Sickness; the formal reports are appropriately indicated in the bibliography. Finally, as frequently the monthly or bimonthly progress reports contain preliminary data of considerable value we have also indexed the subjects as CMR-OSRD Progress Reports. Charts illustrating the more important physiologic data contained in these reports have been grouped together to form a fairly comprehensive report of research carried out in the High Altitude Laboratory of the Mayo Aero Medical Unit.

Oxygen Masks - The first B.L.B. oxygen mask was made by Dr. A. H. Bulbulian in February, 1939 and may be regarded as a forerunner of all subsequent oxygen masks developed at the Mayo Aero Medical Unit. The trial models were made by him in the fully equipped laboratory of the Mayo Foundation Museum of Hygiene and Medicine by the liquid latex or "anode" deposition technic, the method long used by Dr. Bulbulian in making artificial ears, noses, et cetera for patients who had lost them from accident or disease and in making reproductions of interesting and instructive anatomical models. The "anode" method is also used in large scale production of many commercial articles of intricate design. The great advantage of this method lies in the fact that for a comparatively small cost many experimental forms can be made in the laboratory from plaster of paris, low fusing metal, or aluminum. Many new and sometimes radical designs can be constructed, tried out, and either entirely abandoned or repeatedly modified until found suitable and the fit accurate and comfortable. After laboratory and field tests, the final step is then delegated to the manufacturers for the construction of steel molds for large scale production.

The A-8, A-8-A, and A-8-B (Army Air Forces designation) continuous flow oxygen oro-nasal masks, although an adaptation of the B.L.B. clinical masks, were progressively improved for military aviation in collaboration with Capt. (later Colonel) Rudolf Fink, who was at that time in charge of oxygen equipment at Wright Field. These constant flow masks were used by the Air Forces until safe air-oxygen demand valves and masks were developed.

There were a number of intermediate masks developed here which intervened between the A-8-B and the A-14. Type 12 was a continuous flow oxygen mask with chin bag. Type 16 was a clinical mask and the so-called Universal Mask was a type which could be easily converted from the continuous flow to the demand type. The type 17 and 19 had some of the features of the A-8-B and A-14. While none of these masks were used widely, the face fitting features developed in these masks were later in part incorporated in the A-14 demand type mask. The progressive alterations found necessary to prevent freezing and to meet the strict military requirements were made by personal consultation with the members of the Oxygen Equipment Section of the Aero Medical Laboratory, Army Air Forces, Wright Field.

The A-14 mask during its developmental stages went through a series of modifications too numerous to mention. From 1941 to 1943 nearly a hundred experimental soft metal forms were made in the laboratory, and from these forms more than a thousand experimental masks were produced before the final steel production forms were made. Over one million of these masks were produced for the Army and Navy.

One of the last in the series of masks developed at the Mayo Aero Medical Unit, in collaboration with Wright Field, is the A-15 pressure demand oxygen mask, which had finally been perfected and was in the process of going into large scale production in the last months of the war. Some of the basic principles utilized in

the design of the A-15 were described in the Memorandum Report, dated 23 October 1942, to Col. W. R. Lovelace and Col. A. P. Gagge, Aero Medical Laboratory, Wright Field, submitted by Dr. A. H. Bulbulian. Our early laboratory designation for this mask was Type 21 and the Army Air Forces experimental designation was XA-15. A Memorandum Report by Dr. A. H. Bulbulian dated 9 November 1943 on the detail of design and method of molding of the mask is on file.

A Memorandum Report submitted by Dr. Bulbulian on 23 March 1945 presents the contemplated changes in the continuous flow A-8-B mask to make it more useful for certain special purposes desired by Wright Field.

In the development of the whole series of oxygen masks at the Mayo Aero Medical Unit great credit is due to Mr. Allan Russell of the Ohio Chemical and Manufacturing Company and to Dr. J. A. Heidbrink and Mr. R. H. McElrath of the Heidbrink Division. Likewise, the officers and production engineers of the American Anode Company deserve much credit for their continued effort in maintaining a high rate of production in spite of frequent changes and improvements in the forms.

Much of the success of the work carried out in the Mayo Acceleration Laboratory under the direction of Dr. Baldes and Dr. Code has been due to the early establishment of adequate procedures and recording techniques for studying man's reactions to positive acceleration. The importance of the duration of exposure as a factor affecting man's response to acceleration was one of the first problems studied. As a result of these studies a standard acceleration-time exposure pattern was established. In this so-called standard run the acceleration is increased at a rate of approximately 2 g per second and the maximal g level is maintained for 15 seconds. This type of exposure pattern allows the full development of symptoms in man and has given the most complete picture of the effects of positive acceleration as the aviator may experience them.

Using the standard run it was shown that the increased weight of the blood, which occurs as a consequence of the exposure to centrifugal force, initiates a definite sequence of physiologic changes in man. These fall sharply into two distinct periods -- a period of progressive failure followed by a period of compensation. During the period of progressive failure the blood pressure at the level of the head falls, the heart rate increases, the blood content of the ear decreases, the amplitude of the ear pulse is reduced or lost and finally changes in vision or consciousness, if they are to occur, become evident. The period of progressive failure is terminated as a rule by a compensatory reaction which becomes effective about seven seconds after the onset of the force. During the period of compensation the blood pressure rises, the ear pulse improves, the amount of blood in the ear increases and the heart rate slows. If compensation is sufficient, recovery from symptoms will occur. This sequence of events has been observed to occur in each of more than 300 subjects who have been studied in this laboratory.

The maintenance of certain standard conditions under which the tests were performed was also stressed. Early in 1944 an air-conditioning system was provided which made it possible to maintain a constant temperature in the centrifuge room. The effects of warm and cool environmental temperatures on g tolerance were studied, but for routine tests a temperature of approximately 72° F (60 per cent relative humidity) was maintained. Subjects on the centrifuge were asked to maintain a comfortable sitting posture and not to "fight the g." They were requested to put their heads back on a head rest rather than to support them during exposure to acceleration. Every effort was made to determine the subject's "basal" g tolerance

When tests are performed in the manner described, trained subjects on the Mayo centrifuge on the average experience dimming of vision at approximately 3 g, loss of peripheral vision at 3.5 g, complete loss of vision at 4.0 g and unconsciousness at accelerations of 4.5 g or more. The standard deviation of the average g tolerance of individuals (inter-individual difference) is 0.6 g, while the standard deviation of the g tolerance of one individual (intra-individual difference) is 0.4 to 0.5 g.

Study of the details and inter-relations of the symptoms and physiologic changes which occur during exposure to positive acceleration was facilitated by a recording system which allowed the continuous and simultaneous registration of more than 12 variables (time, acceleration, arterial pressure measured by arterial puncture or by an indirect method, venous pressure, ear pulse, ear opacity, electrocardiogram, heart rate, respiration, intra-rectal pressure, the subject's reaction time to light signals in his peripheral and central fields of vision, motion pictures or still photographs of the subject, anti-blackout suit pressures and others). Using these techniques observations were made on over 300 subjects (laboratory personnel and civilian and Army volunteers) in over 10,000 exposures to acceleration under standard conditions and with various protective devices and procedures.

The recognition of the sequence of physiologic changes which occur in man during exposure to positive acceleration and the regularity of their occurrence allowed an orderly and quantitative approach to the problem of protecting the aviator. Upon the basis of these changes a bio-assay procedure was developed which allowed accurate determination of man's g tolerance and the protective value of any device or procedure designed to offset the deleterious effects of positive acceleration. The assay procedure was based upon the recognition and determination of the g level at which various subjective symptoms occur (dimming of vision, loss of peripheral vision and complete loss of vision) and upon the measurement of certain objective changes in the subject (loss of blood from the ear, reduction or loss of the blood pulsations in the ear, degree of pulse rate increase and magnitude of blood pressure changes) during exposure to various amounts of acceleration with and without the protective device or procedure (Figure 1).

The study of methods whereby the ability of aviators to withstand positive acceleration could be increased was divided into three categories: (1) limitation of duration of force, (2) changing the position of the pilot to reduce the hydrostatic distances between the heart and head, and (3) increasing arterial pressure.

Limitation of the duration of the force and other changes in the acceleration-time curve which might allow the aviator to experience high accelerations without symptoms were studied but were not considered a practical solution to the problem of blackout because of the limitation they imposed on the combat maneuvers which the pilot could perform. Studies were carried out on the protective value of the crouch and prone positions and of tilting seats. These procedures, while effective, restricted the activity of the pilot in his cockpit and were likewise not accepted as a practical solution for the immediate emergency.

It became evident that the most practical anti-blackout procedure for pilots in World War II would be one which would require no attention on the part of the pilot and would allow him full freedom of activity in the normal sitting position. A very effective straining maneuver (M-1) was developed which increased arterial pressure and enabled pilots to maintain accelerations up to 8 or 9 g in the sitting position. While this was effective, the procedure was considered only a stop-gap or emergency procedure and not a satisfactory solution to the blackout problem because it increased the pilot's fatigue and required his concentrated attention.

In 1942 efforts were directed to the development of anti-blackout suits. Also comparative tests were made on suits which were being developed elsewhere at that time, particularly the Navy Gradient Pressure Suit and the Canadian Frank's Flying Suit. Mr. F. Moller, Mr. I. R. Versoy and Mr. S. M. Berger of the Berger Brothers Company cooperated in some of the tests on the Gradient Pressure Suit (Navy GPS or Army G-1). The GPS and FFS were designed to prevent pooling of venous blood below the heart during exposure to positive acceleration. However, our records of the cardiovascular changes which occurred during exposure to positive acceleration on the centrifuge did not confirm the concept that pooling of venous blood was the dominant or chief factor limiting man's g tolerance. After several seconds' exposure to acceleration, arterial pressure rose and recovery from symptoms occurred even though acceleration was continued. We realized that this compensation could not have occurred if pooling of blood were the critical factor.

Attention was then directed to the development of anti-blackout suits designed primarily to increase arterial pressure. Dr. E. H. Wood was most closely associated with the development of anti-blackout suits carried out in the Mayo Acceleration Laboratory, although the other members of the laboratory participated from time to time. In the construction of the anti-blackout suits collaboration with Mr. David Clark of the David Clark Company, Worcester, Massachusetts had been underway since April, 1942. Mr. Clark had been working on the construction of anti-blackout suits independently up to that time. By the spring of 1943 two suits had been constructed which by applying arterial occlusive pressures to the extremities and pressure to the abdomen increased the blood pressure at heart level and directed cardiac output towards the head during the critical periods of exposure to centrifugal force. The Progressive Arterial Occlusion Suit (PAO, Mayo Models 1 and 2) was tested on the centrifuge in November, 1942, and the Simple Arterial Occlusion Suit (AOS, Mayo Models 3 to 9) was first tested on the centrifuge in February, 1943. These suits were found capable of increasing the g tolerance of centrifuge subjects by as much as 3 g. They are still the most effective anti-blackout suits which have been developed. The AOS was extensively

tested by the Army Air Forces (Dr. Wood assisted in many of these tests), but were not accepted for use because the pilots objected to the discomfort caused by the high pressure to which the suits were inflated in order to obtain a 3 g protection.

Late in 1943 it became evident from observations made by the Navy and Army on the use of anti-blackout suits in field trials and in combat that pilots needed only a moderate increase in their g tolerance to avoid blackout in the aircraft in use in World War II and that pilot acceptance particularly from the standpoint of comfort was a most important requirement for an anti-blackout suit. Basic information which had been obtained up to this time from studies on the centrifuge using the GPS, FFS and AOS made it possible to outline the factors which are important in the protection afforded by anti-blackout suits. As a result in January, 1944 a simple bladder system was constructed by Mr. Clark and Dr. Wood that could be put into any type garment which would allow transmission of pressure by the bladder system to the important parts of the body. Numerous modifications of the outer garment (M-10 to M-22, the nylon bladder suits) were tested on the centrifuge. All of these contained the simple basic bladder system and all were effective anti-blackout suits. The principle of the simple bladder system was accepted by both the Army and the Navy and was employed in garments designed to fulfill the particular requirements of their pilots in different war theaters. The Navy in collaboration with the David Clark Company developed a coverall garment (Navy Z-1 and Z-2 suits, Army G-4) while the Army in collaboration with the Berger Brothers Company, New Haven, Connecticut and the David Clark Company developed the cutaway or skeleton suit (Army G-3, Navy Z-3). These suits increase the g tolerance of centrifuge subjects by 1 to 1.5 g. The protection against blackout which they afford has been shown by experiments carried out in the Mayo Acceleration Laboratory to be due to the increase in blood pressure which they produce.

The development of inflating valves for the anti-blackout suits was carried out simultaneously with the development of the suits themselves. Early models were developed in collaboration with the Heald Valve Company, Worcester, Massachusetts (particularly for the AOS) and the Cornelius Company, Minneapolis, Minnesota. In the spring of 1944 Mr. Richard Cornelius designed, built and submitted for test the antecedent of the present C-C-1 valve. With little modification this valve was accepted as their standard valve by the Navy and as an alternate standard by the Army. A large amount of work was done in the Mayo Acceleration Laboratory to establish the performance characteristics of inflation systems under all flight conditions and to set down the requirements for adequate anti-blackout suit inflation.

In June, 1944 the Mayo Acceleration Laboratory extended its studies of blackout to include controlled observations made in aircraft, under the direction of Dr. E. H. Lambert, in order to determine in detail the applicability of human centrifuge observations to the pilot in flight. An RA-24 A (SBD-4) Douglas dive bomber was assigned to the Mayo Aero Medical Unit by the Army Air Forces at the request of the Aero Medical Laboratory at Wright Field. Recording equipment in part supplied by the National Research Council (OSRD) was installed for making physiologic studies of pilots and passengers in flight (Figure 2). The plane was stationed at the Rochester Airport (Minnesota). Lt. Kenneth R. Bailey, engineering

officer of the Air Transport Command Station at the Rochester Airport, volunteered to assist in these tests, and his participation as pilot of the plane and as supervisor of its maintenance was made possible by Brigadier General Bob E. Nowland, Commanding General of the Ferrying Division. In the fall of 1945 a second plane (SBD-6) was assigned to the laboratory by the U.S. Navy through the Aero Medical Laboratory at Wright Field to replace the then obsolete A-24. This plane was also equipped for recording physiologic events during acceleration and at the end of the war was returned to Wright Field for continuation of these studies by the Army Aero Medical Laboratory.

The studies carried out in the airplane fully substantiated the fundamental results which were obtained on the human centrifuge. Pilots performing maneuvers which produced an acceleration-time curve similar to that used on the centrifuge experienced visual symptoms and showed the changes in the ear pulse, blood content of the ear and pulse rate which were the same as those observed in subjects on the human centrifuge. The principal difference between men piloting the airplane and subjects on the centrifuge was in their g tolerance. Pilots on the average experienced dimming of vision, loss of peripheral vision and blackout at 4.7, 5.1 and 5.5 g, respectively, and lost the ear pulse at 5.3 g. This was on the average 0.7 g higher than the g tolerance of airplane passengers and 1.4 g higher than the g tolerance of subjects on the Mayo centrifuge. Among the factors contributing to the higher g tolerance of the pilots were: (1) the "excitement of flying", (2) the crouching position when piloting, (3) the effort of pulling the control stick to execute the high g maneuver, and (4) the colder temperatures in the airplane.

Despite the higher control g tolerance of pilots without protection, the increase in g tolerance which they were afforded by anti-blackout suits was the same as that afforded subjects on the centrifuge. This observation corrected an impression based on poorly controlled field trials that the standard anti-blackout suits provided 2 or 3 g or even unlimited protection against blackout, when in fact they afforded only 1 to 1.5 g protection. The suits were nonetheless satisfactory in the fighter planes of World War II. At the higher accelerations which were reached with the suits on, the majority of pilots did not or could not sustain the peak accelerations of combat maneuvers long enough to produce definite visual symptoms. Straining on the part of the pilot probably further increased the apparent effectiveness of the suits.

These controlled observations made in the airplane effectively rounded out the program of the Mayo Acceleration Laboratory by demonstrating that the fundamental information obtained from centrifuge experimentation could be applied with confidence to the conditions of actual flight.

From time to time aspects of the problem of acceleration other than those dealing with the effects of positive acceleration were studied in the Mayo Acceleration Laboratory. The ability of man to move and to don a parachute when exposed to accelerations of up to 2 to 3 g was studied on the centrifuge. These studies illustrated the difficulty experienced by aviators attempting to escape from spinning aircraft. Experiments were performed on a vertical centrifuge to study man's reactions to unusual accelerations which, it was anticipated, might be encountered in certain types of aircraft then in the stages of development.

A more complete description of the procedures and recording techniques used and of the physiologic studies and anti-blackout suit development which were carried out in the Mayo Acceleration Laboratory is being prepared for the monograph on acceleration to be published by the Subcommittee on Acceleration. A review which covers many of the principle contributions during the war of all the acceleration laboratories of the United States, Great Britain, Canada and Australia was prepared by the Mayo Acceleration Laboratory for a symposium on "Some Contributions to the Solution of War Problems" which was presented before the American Physiological Society in 1946.

Several extramural projects of considerable magnitude were carried out by the staff of the Mayo Aero Medical Unit with the approval of the Mayo Properties Association in conjunction with the Army Air Forces and the Subcommittee on Acceleration of the National Research Council.

Dr. E. J. Baldes was appointed in 1941 as Special Consultant to the Air Technical Service Command at Wright Field and spent considerable time throughout the war on special missions connected with acceleration and deceleration, the chief of which are listed below. For this work he was awarded on August 31, 1945 at Wright Field by Brigadier General L. C. Craigie on behalf of the Secretary of War the following citation:

War Department
Commendation for Exceptional Civilian Service
To Whom It May Concern:

Edward J. Baldes
has received official commendation and praise for
exceptional performance of duty

Citation:

In recognition of his outstanding service to the Army Air Forces and the nation's war effort in the design of special centrifugal devices. His exceptional ability and untiring efforts have contributed immeasurably to the flying safety of American aviators and have provided the Army Air Forces with the finest scientific knowledge available.

Henry L. Stimson
Secretary of War

Shortly after Major Lovelace made, on June 24, 1943, his epoch making parachute jump from 40,200 feet for which he was awarded the Distinguished Flying Cross, studies on deceleration forces involved in parachute jumps at high altitudes were initiated by him at the Air Technical Service Command of the Army Air Forces at Wright Field. Dr. Baldes was requested to undertake this investigation. As no recording instruments were available the first problem was to design, in conjunction with Professor J. J. Ryan and Dr. B. Lindquist of the University of Minnesota, an appropriate recording tensiometer. As soon as recording

instruments were available extensive data were quickly obtained by parachute experiments at Muroc, California in cooperation with Captain Hallenbeck and other officers from Wright Field. These studies later were correlated with the Subcommittee on Deceleration of the National Research Council and finally resulted in an entire revision of the heretofore accepted assumptions in regard to the magnitude of the forces involved.

In the fall of 1944 Dr. E. J. Baldes as Special Consultant of the Air Technical Service Command was sent on a special mission to the Southwest Pacific Theater to assist in the indoctrination of Air Force Squadrons in the use of anti-g suits in part developed at the Mayo Aero Medical Unit and also to obtain suggestions from the fighter pilots as to their possible improvement. The trip was extended on behalf of the National Research Council to Australia to consult with the scientists and officers of the acceleration group of the Royal Australian Air Force.

Dr. Baldes also worked on problems connected with deceleration as a member of a special Subcommittee of the Committee on Medical Research in conjunction with the Aero Medical Laboratory at Wright Field. The solution of the problems of deceleration has a wide application not only in aviation but also in transportation in general. Therefore, it is hoped that these studies will be continued.

At the request of the Army Air Forces and the National Research Council Dr. E. J. Baldes was sent on a special mission to the European Theater shortly after the Germans surrendered to assist in obtaining the reports of the investigations of the various German civilian and military research laboratories on the problems of acceleration and to obtain full details of the German ejection seat. A large number of German reports were brought back by him and by Colonel Lovelace, and many of these were translated at the Mayo Aero Medical Unit under the supervision of Dr. Bateman.

In the spring of 1946 Dr. Baldes was requested by the Army Air Forces to proceed again to the European Theater to obtain still more data from the German research laboratories and the German scientists. On this trip he was accompanied by Dr. E. H. Wood of the Mayo Aero Medical Unit who was also made a "Special Consultant."

LEGENDS

Figure 1: An example of records obtained in routine studies on the human centrifuge. The records shown are taken from an assay of the protective value of the G-2 suit inflated with a pressure approximately 1.0 p.s.i. per g. To determine the protective value of any suit or device against the effects of acceleration, tests are conducted in the manner of a bioassay using man as the test object. Exposures to acceleration with inflation of the anti-blackout suit are preceded and followed by runs without the suit. A subjective estimation of the effectiveness of the suit is obtained using visual symptoms as an end point, while the decrease in amplitude of the ear pulse, the decrease in blood content of the ear (E.O.) and the increase in pulse rate are used for objective measurement of protection. In the run shown the subjective symptoms were as follows:

Control runs:

Run 2AAD- 1: 2.5 g for 15 seconds.
Vision clear.

Run 2AAD-16: 4 g for 15 seconds.
Peripheral lights lost from 5.5 to 11.5 seconds.
Center light lost from 8 to 12 seconds (blackout).

Protected runs, single pressure suit:

Run 2AAD- 8: 4 g for 15 seconds.
Vision clear.

Run 2AAD- 7: 6 g for 15 seconds.
Peripheral lights lost from 6 to 17 seconds.
Center light lost from 8.5 to 17.5 seconds (blackout

In the entire series of 16 runs in this assay on Subject 2, protection against visual symptoms was about 1.3 g, against a decrease in blood content of the ear 1.7 g, and against a decrease in amplitude of the ear pulse 2.4 g.

Figure 2: An example of the records obtained from studies carried out in the A-24 airplane. This composite shows the effect of 5.0 g positive acceleration on a passenger in the airplane. The photographs are enlargements from a 16 mm. motion picture film. The middle tracing was obtained from the oscillographic unit recording the ear opacity, ear pulse, etc. The lower record shows the g-time pattern recorded by the R.S. recording accelerometer. The black lines synchronize the motion pictures with the other records. The subject stated that he blacked out in this run. He was apparently disoriented for several seconds after the run. Note the failure to respond to the light signals. Note that the ear pulse is almost lost.

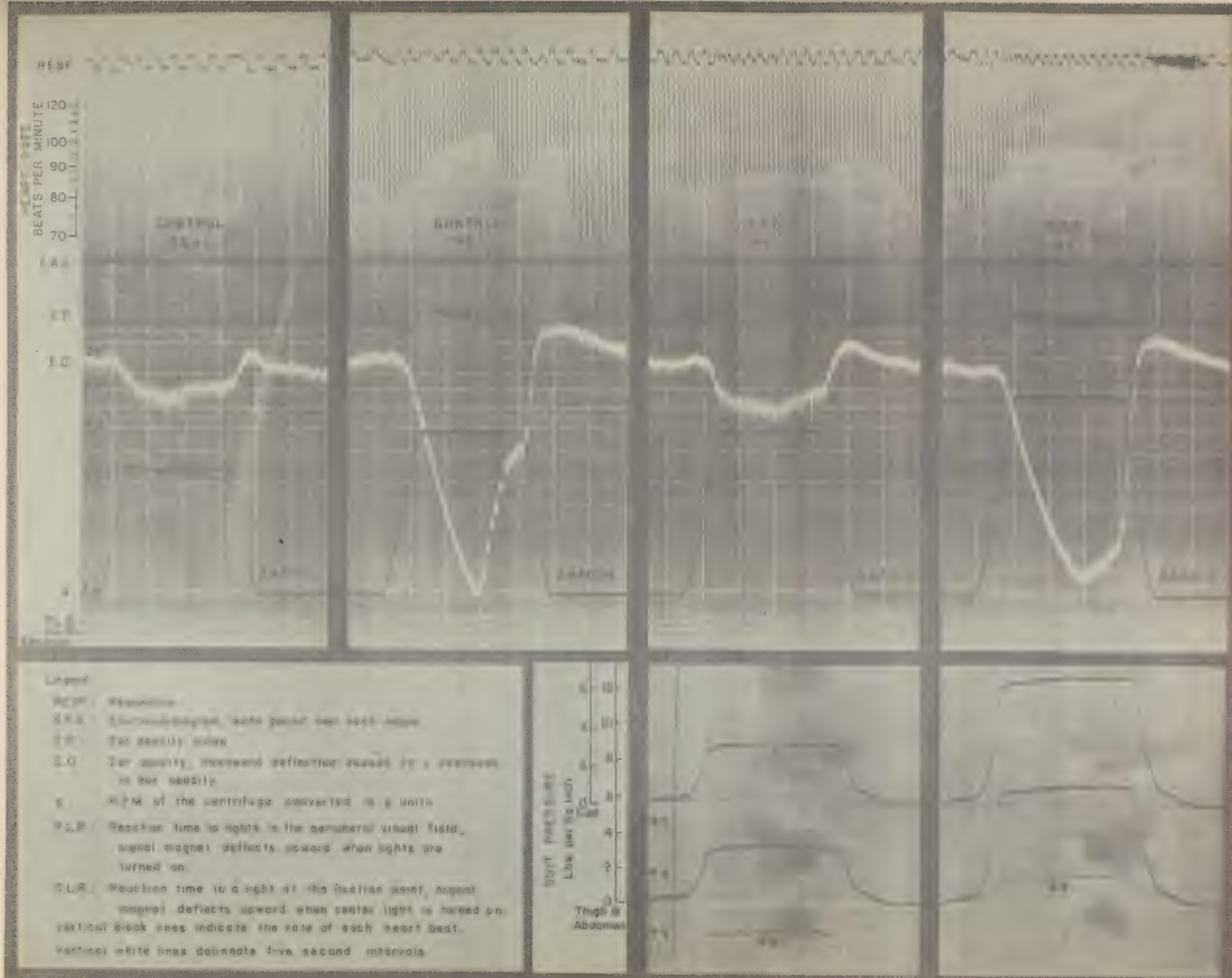

RESP
HEART RATE
BEATS PER MINUTE
120
100
90
80
70
E.O.
SUIT PRESSURE
Lbs per Sq Inch
Thigh &
Abdomen
0
2
4
6
8
10
12
Legend
R.P.M. of the centrifuge converted to g units
Reaction time to lights in the peripheral visual field, signal magnet deflects upward when lights are turned on.
C.L.R.: Reaction time to a light at the fixation point, signal magnet deflects upward when center light is turned on
Vertical black lines indicate the rate of each heart beat.
Vertical white lines delineate five second intervals

Fig. 1

SUBJECT 26, UNPROTECTED, PASSENGER IN A-24 AIRPLANE
5.0 g
(Symptoms: "Blackout", Disorientation)

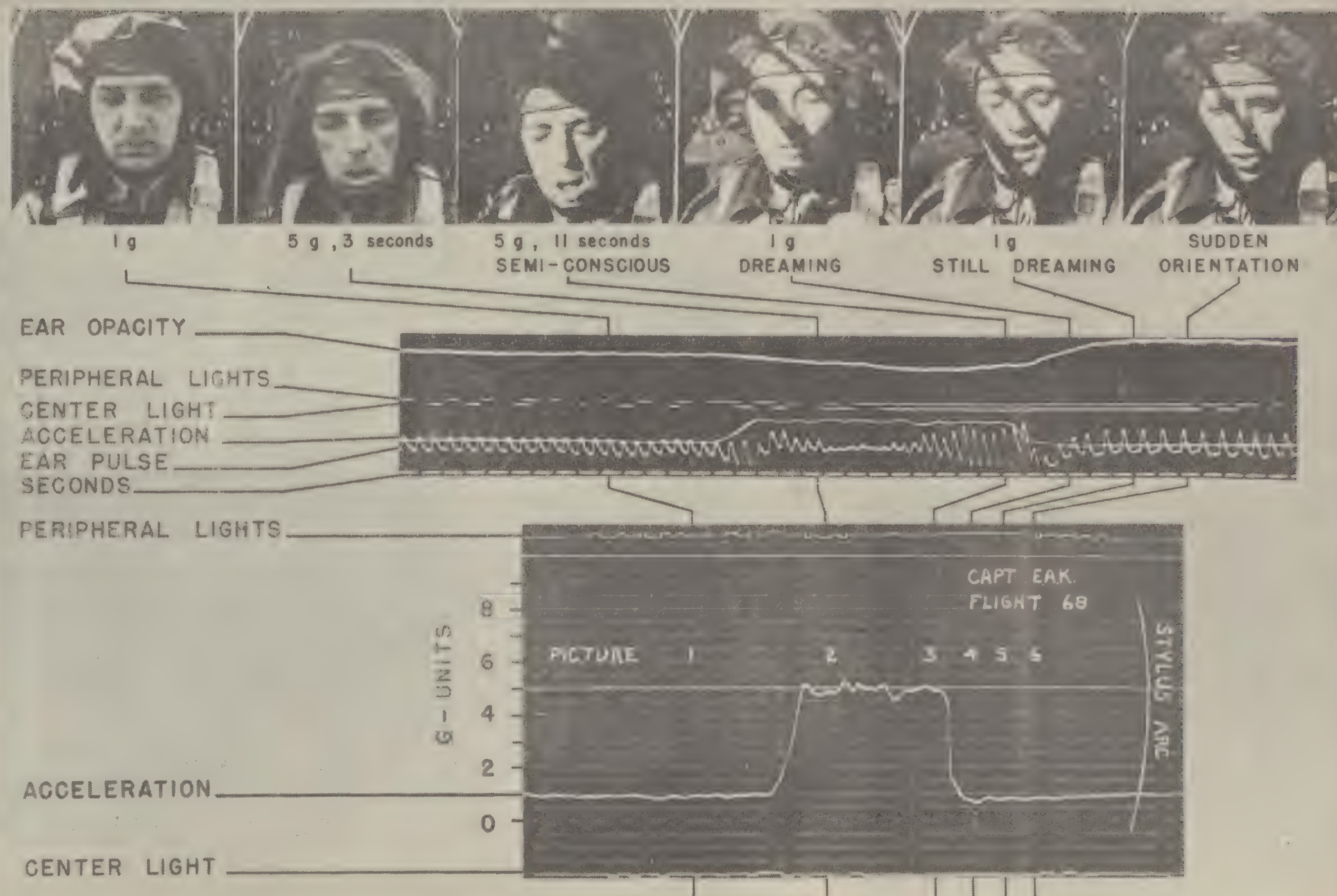


Fig. 2

FIRST TESTING OF BLB MASK IN LOW PRESSURE CHAMBER USING RATES OF OXYGEN FLOW CALCULATED TO MAINTAIN NORMAL ALVEOLAR pO_2
(Preliminary ~~Denitrogenation~~)

April 11, 1938 Wright Field Aero Medical Laboratory Low Pressure Chamber
Captain Harry Armstrong, Chief; Dr. Heim, Scientific Associate

Object of the pressure chamber flight is to test the efficiency of the BLB nasal mask with 500 cc. reservoir bag with metal connector containing 4 holes which could be closed or opened by a revolving sleeve. The floows of oxygen which were used at the various altitudes were considered by Boothby and Lovelace to be theoretically sufficient to maintain a normal alveolar air. Such low rates of flow had never before been tried except once in a nitrogen chamber.

Dr. Heim in the absence of Capt. Armstrong was in charge of the low pressure chamber and extended to Dr. Boothby and Dr. Lovelace every courtesy and assistance. Dr. Lovelace was the subject of the experiment. Dr. Boothby was outside the chamber to regulate the oxygen flow so that the desired amount would be obtained. For this purpose the oxygen was passed through a 10 liter gas meter at room temperature and ground barometric pressure to give the desired rate of flow after correction to STPD. The oxygen flowed into the chamber through a special valve inserted for the purpose of preventing suction on the gas meter.

A few days previous to this experiment Dr. Heim had collapsed and become paralyzed for a short time on a flight in the low pressure chamber at about 30,000 feet. After discussion of the various factors that might cause collapse it was concluded that aero-embolism was a possible if not probable explanation. To avoid such a complication as aero-embolism from obscuring the results of the main object of the experiment Dr. Lovelace breathed pure oxygen for approximately one half hour during the preliminary preparations for the flight to reduce the body nitrogen especially as during the flight he was to breathe an air-oxygen mixture of a composition calculated to maintain only a normal tracheal pO_2.

Accompanying Dr. Lovelace in the flight was Private Whitney who received throughout approximately 10 liters of oxygen per minute (STPD) and wore the ordinary laboratory mask which he had worn on previous chamber flights. He used the same equipment as he did on the flight when Dr. Heim had collapsed; and as he had had no difficulty during that or other flights he did not denitrogenize for this flight. Furthermore, the ascent was to be relatively slow and he was to be supplied with a large excess of oxygen so that he would be breathing approximately pure oxygen from the ground up.

Throughout the experiment Dr. Lovelace appeared perfectly normal and showed no cyanosis or other evidence of anoxia although he was fairly active inside the chamber especially when attempting to obtain alveolar air samples unaided. Both the CO_2 and O_2 pressures were slightly below normal. The alveolar air sample obtained at 20,000 feet indicated the subject had an alveolar oxygen pressure which we now know to be equivalent to about 7,500 feet without oxygen. The alveolar air obtained at 27,000 feet was slightly higher and equivalent to about 6,000 feet without oxygen. The CO_2 pressure indicated a slight degree of hyperventilation not sufficient to cause any symptoms of acapnia but comparable to what might be expected on a "first time." At no time was there the slightest evidence indicating bends in either subject.

(The above report has been somewhat amplified from the original notes.)

(over)

April 11, 1938. Experiment in low pressure chamber at Wright Field, Dayton, O.

Time Minutes	Elevation Feet	Oxygen flow Liters/min. STPD		Alveolar Air Pressure	
		Amount desired	Amount actually delivered	pCO_2 (mm. Hg)	pO_2 (mm. Hg)
10.40	Ground	1.0	0.9		
10.50	10,000	1.0	0.9		
11.16	20,000	1.0	0.9		
11.20	20,000	1.0	0.9	(1) 31 (2) 31	(1) 70 (2) 71
11.35	20,000	1.5	1.4		
11.38	21,000	1.5	1.4	(1) 31 (2) 29	(1) 76 (2) 74
11.41	22,000	1.5	1.5		
11.47	27,000	1.5	1.5	(1) 31 (2) 29	(1) 76 (2) 74
12.04	28,000	1.5	1.5		
12.11	30,000	1.5	1.4		
12.28	33,000	1.5	1.5		
12.39	Started down because Dr. Heim did not wish to have the subject go higher on account of the recent accident possibly to aeroembolism				
1.15	Ground				

Temperature of meter average 77° F. Barometer 747.3

Dr. Lovelace denitrogenated for approximately 1/2 hour previous to ascent.

TESTING BLB MASKS AND OXYGEN SUPPLY EQUIPMENT IN COMMERCIAL AIRPLANES

Northwest Airlines was the first commerical
line to install efficient oxygen equipment.

Date .... July 28, 1938. Reference: San Francisco Examiner July 30, 1938.
Airplane .... Northwest Airlines, Lockheed Sky Zephyr.
Destination ..... Minneapolis via Billings to Los Angeles - 1900 miles.
Mask .... BLB, nasal mask of light brown rubber, with metal valve on connector to reservoir bag.
Chief pilot ..... Mal Freeburg. Co-pilots: Mel Swanson and B.E. Richie.
Passengers ...... W.R. Lovelace and six NWA engineer personnel.
Altitude .... 20,000 feet for greater portion of flight.
Object of trip .. To test new oxygen equipment for use by pilots and passengers and new type reducing valve which feeds correct amount of oxygen to maintain a normal tracheal pO_2 regardless of number of persons whose oxygen masks are connected to oxygen supply.

Date .... August 5, 1938. Reference: Minneapolis Tribune.
Airplane .... Northwest Airlines, Lockheed Sky Zephyr.
Destination ..... Los Angeles to Minneapolis in 7 hours and 40 minutes.
Mask .... BLB, nasal mask of light brown rubber, with metal valve on connector to reservoir bag.
Chief pilot ..... Mal Freeburg. Co-pilot: Mel Swanson and B.E. Richie.
Passengers ...... W.R. Lovelace and two NWA personnel.
Altitude .... 1/3 of flight at 30,000 feet; maximum 31,400 feet.
Object of trip .. To test new oxygen equipment for use by pilots and passengers and new type reducing valve at high altitudes.

Date .... August 20, 1938. Reference: St. Louis Post Dispatch.
Airplane .... Howard Hughes - Lockheed 14 monoplane.
Destination ..... Glendale, Calif. to Floyd Bennett Field, N.Y.
Mask .... BLB, nasal mask of light brown rubber, with metal valve on connector to reservoir bag.
Chief pilot ..... Howard Hughes.
Passengers ...... Three companions.
Altitude .... Average elevation 17,000 feet and maximum elevation 20,000 feet.
Object of trip .. Record for speed - average of 238 miles per hour in 10 hours and 32 minutes. This record is over Tommy Tomlinson (11 hours, 5 minutes) 4 years ago.

Date .... October 27, 1938. Reference: Rochester Post Bulletin.
Airplane .... Vanderbilt's Lockheed Zephyr.
Destination ..... One and one half hour flight over Rochester and vicinity.
Mask .... BLB, nasal mask of light brown rubber, with metal valve on connector to reservoir bag.
Chief pilot ..... Russel Thaw.
Passengers ...... W.M. Boothby, W.R. Lovelace, A. Uihlein, Ruth Knutson and 3 other personnel.
Altitude .... Maximum altitude 15,450 feet.
Object of trip .. The oxygen distribution equipment was installed at the Lockheed factory in Los Angeles. The Rochester flight was made to test the installation of the oxygen equipment.

Date.............. February 20, 1939. Reference: Minneapolis Journal.
Airplane .... Northwest Airlines - Lockheed Sky Zephyr.
Destinatior ..... Minneapolis to Little Falls.
Mask .... BLB, nasal mask of black rubber, with metal valve on connector to reservoir bag.
Chief pilot ..... Mel Swanson, Co-pilot: Tom Chastain
Passengers ...... W.R. Lovelace and 5 other NWA personnel.
Altitude .... 15,000 to 20,200 feet.
Object of trip .. To test the new BLB oxygen mask and oxygen distribution equipment that will be installed on all Northwest Airlines planes for use of pilots and passengers when necessary.

Date .... March 10, 1939. Reference: Boston Evening Transcript.
Airplane .... Northwest Airlines - Lockheed Sky Zephyr.
Destination ..... Minneapolis to Boston, Washington, Indianapolis and back to Minneapolis.
Mask .... BLB, nasal mask of black rubber, with metal valve on connector to reservoir bag.
Chief pilot ..... Mal Freeburg. Co-pilot: Eric Jaselk.
Passengers ...... W.M. Boothby, W.R. Lovelace, A. Uihlein, A. Bulbulian and six other passengers.
Altitude .... 15,000 feet to 23,000 feet.
Object of trip .. To demonstrate the efficacy of the BLB oxygen mask and oxygen equipment as installed in a commercial airliner to special meeting on Aviation Medicine at the Harvard University Fatigue Laboratory. It was the first public demonstration of an oxygen equipped commercial passenger plane intended for regular passenger service.

The equipment was inspected at Boston, New York and Washington by various officials concerned with the safety of the crews and passengers in prolonged flights at the higher altitudes.

SCIENTIFIC MEETINGS AND DEMONSTRATIONS

Dec. 28, 1939 - Columbus, Ohio. The American Association for the Advancement of Science. W. M. Boothby, W. R. Lovelace, II and O. O. Benson, Jr. (Science Service, for release Dec. 29, and A.P. in Minneapolis Tribune Dec. 29,1939)

At this meeting the first public discussion was made of the value of preliminary denitrogenation both with and without exercise before high chamber flights.

Jan. 8, 1940 - Toronto University, R.C.A.F. Research Group. Prof. G. E. Hall, Chr.

Discussions by W. M. Boothby, W. R. Lovelace, II and O. O. Benson, Jr. (1) on value and advisability of preliminary denitrogenation for high flights, (2) on rates oxygen flow needed with BLB mask and reservoir bag to maintain normal tracheal pO_2 at rest breathing 10 liters per minute and at light and moderate work when breathing 20 to 30 liters per minute. Following the demonstration at Toronto Prof. Hall and Major Tice, R.C.A.F.,visited our laboratory on Jan. 15 to 17, 1940. They made several flights (Nos. 50, 51 and 52) to 40,000 feet in the low pressure chamber with and without denitrogenation; electrocardiographic records and alveolar air studies were made.

Mar. 15, 1940 - New Orleans. Scientific Exhibit of the Federated Biological Societies.

W. M. Boothby, W. R. Lovelace, II and O. O. Benson, Jr. demonstrated methods of denitrogenation, of bail-out bottle and of charts illustrating rates of flow needed with BLB apparatus at rest and at light work calculated to maintain normal tracheal pO_2.

April 24, 1940 - Mayo Aero Medical Unit special demonstration for Major (later Lt. Gen.)Doolittle and Major Lester O. Gardner (retired) Institute Aeronautical Sciences. (Minneapolis Tribune April 24, 1940)

Preliminary denitrogenation with ascent to 40,000 feet made by Major Doolittle and Captain Benson, Jr.; the latter made a simulated parachute jump with recently devised bail-out bottle (Flight No. 82).

May 15, 1940 - University of Western Ontario, Canada. (Toronto Globe May 16, 1940)

Lecture by W. M. Boothby on "The clinical uses of oxygen and its application to aviators," in which preliminary denitrogenation and the bail-out bottle were discussed.

May 27, 1940 - Mayo Aero Medical Unit.

The first experiments to determine with greater exactness the rate of nitrogen elimination were made by W. M. Boothby, W. R. Lovelace, II and O. O. Benson, Jr. with subject (O.O.B.) at sitting rest and at work (walking on the treadmill at 3 miles per hour). The average results of the series of experiments were first published in "Physiology of Flight," Wright Field, 1940-42, page 27. The graph in this publication was made on semi-log paper to indicate the probable asymptote; the data of the individual experiments when plotted on log-log paper lie in nearly all instances on a straight line over periods of 2 to 3 hours.

June 22, 23, 1940 - Seattle, University of Washington, Branch meeting of the American Association for the Advancement of Science and at Boeing Aircraft Corporation.

During lecture by W. M. Boothby in high altitude physiology W. R. Lovelace, II demonstrated method of preliminary denitrogenation, then ascended to 40,000 feet in a small portable low pressure chamber using BLB mask, reservoir bag and recommended rates of oxygen flow; descent was very rapid (not explosive) from 40,000 feet to ground level in 40 seconds.

June 26, 1940 - Pasadena, California, California Institute of Technology.
(Lecture and demonstration of June 22 repeated.)

Sept. 26, 1940 - Washington, D.C., National Aeronautical Association at the Willard Hotel.

A complete exhibit and demonstration of all phases of the high altitude studies carried out at the Mayo Aero Medical Unit were made to the members of the Collier Trophy Committee and other officers of the National Aeronautical Association. Miss Jacqueline Cochran, who was one of the members of the Collier Trophy Committee, made all the arrangements for this demonstration after she visited the Mayo Aero Medical Unit in August 1940.

Dec. 4, 1940 - Washington, D. C., White House.

President Roosevelt personally presented the Collier Trophy on behalf of the National Aeronautical Association at noon on Tuesday, December 17, 1940 with the following award:

"The NATIONAL AERONAUTIC ASSOCIATION awards
herewith the COLLIER TROPHY, aviation's highest civil
honor, for the year 1939 to the AIRLINES OF THE
UNITED STATES for their high record of safety in air
travel, with special recognition to
DOCTOR WALTER M. BOOTHBY
DOCTOR WILLIAM RANDOLPH LOVELACE II
of the Mayo Foundation for Medical Research
and Education, and to
CAPTAIN HARRY C. ARMSTRONG
of the U.S. Army Medical Corps at Wright
Field, for their contribution to this safety record
through their work in aviation medicine in general
and pilot fatigue in particular.
Done at Washington, D. C. on the seventeenth
day of December, Nineteen hundred and forty.
Gile Rosh Wilson G. de Forest Lerner
President Secretary"

Dec. 1940 - Mayo Aero Medical Unit. X-rays of Joints.

During this month several series of x-rays were taken at 40,000 feet of various painful joints of Dr. Harold Smedal. Definite indication of air in the wrist joint was obtained. One set of experiments are reproduced in Fig. 14a and 14b, page 26 of "Physiology of Flight," Aero Medical Research Laboratory, Wright Field, 1940-42.

Jan. 29, 1941 - Columbia University, Annual meeting of the Institute of Aeronautical Sciences. (Reported in New York Times Jan. 29, 1941)

W. M. Boothby and W. R. Lovelace, II showed a motion picture of some of their activities in working to overcome anoxemia and aeroembolism.

Sept. 1942 - Indianapolis, Ind. Closed session of the Aero Medical Association.

First statistical study of which we were aware of the value of denitrogenation as recommended by Mayo Aero Medical Unit in actual flight was presented by Dr. Russell and Mr. Michael of the Boeing Aircraft Company. Part of this presentation, with additional data, was included in a mimeographed and confidential report on "High Altitude Flying" at the Boeing Aircraft Company. Method of denitrogenation used with exercise shown by pictures in Boeing News of May, 1941, Vol. XI, No. 5.

MAYO AERO MEDICAL UNIT

EARLY FLIGHTS IN LOW PRESSURE CHAMBER

Flight 1, May 26, 1939
The first run in the low pressure chamber of the Mayo Aero Medical Unit was a slow ascent (1 hour 23 minutes) to 15,500 feet (S.O.F.)*

Flight 2, May 29, 1939
Ascent to 20,000 feet (S.O.F.) - no symptoms reported

Flight 3, June 5, 1939
Ascent to 30,000 feet (S.O.F.) - no symptoms reported

Flight 4, June 6, 1939
Ascent to 30,000 feet (S.O.F.) - no symptoms reported

Flight 5, June 7, 1939
Ascent to 30,000 feet (S.O.F.) L.C. reported a smarting of eyes after passing 20,000 feet; note was made that the smarting and gritty sensation was considered as possibly a manifestation of bends due to small superficial corneal bubbles.

Flight 6, June 9, 1939
Ascent to 30,000 feet (S.O.F.) and no symptoms reported

Flight 7, June 12, 1939
Ascent to 30,000 feet (S.O.F.) and no symptoms reported

Flight 8, June 13, 1939
Ascent to 30,000 feet (S.O.F.) L.C. reported itching of skin and N.D. smarting of eyes at 30,000 feet.

Flight 9, June 14, 1939
Ascent to 30,000 feet (S.O.F.) and no symptoms reported

Flight 10, June 15, 1939
L.C. reported "light headedness" at 35,000 feet (S.O.F.) (bends was considered, no anoxia)

Flight 11, June 19, 1939 Denitrogenated.
First preliminary denitrogenation by breathing 100% oxygen at sitting rest for approximately 1 hour followed by ascent to 33,000 feet (S.O.F.); notes in log: "eyes, skin o.k., moderate gas pains, no fatigue and not sleepy."

This marks the beginning of the nearly routine use of denitrogenation before chamber flights on which the intention was to go above 30,000 feet; later if the flight was to be short some runs were made without denitrogenation. At the Mayo Aero Medical Unit subjects were scarce and we felt it safer to prevent the extra fatigue which our subjects noted if they did not denitrogenate; we never had sufficient subjects to determine statistically the frequency of bends. We also began to recommend preliminary denitrogenation to test pilots of the various aircraft manufacturers who were testing the new high altitude aircrafts.

* S.O.F. = Standard Oxygen Flow: These flows based upon maintaining a normal tracheal pO_2 were later recommended by Boothby, Lovelace and Benson, Chart I-1, Mayo Aero Medical Unit; also J. Aeronaut. Sci., 7: 465, Sept. 1940.

Flight 12, June 20, 1939 Denitrogenated.
Denitrogenated for 1 hour on 100% oxygen at sitting rest. On ascent to 33,000 feet (S.O.F.) slight gas pains (bend symptoms mentioned).

Flight 13, June 21, 1939 Denitrogenated.
Denitrogenated for 56 minutes on 100% oxygen at sitting rest. On ascent to 35,000 feet (S.O.F.) no significant symptoms.

Flight 35, Nov. 28, 1939 Denitrogenated.
Denitrogenated for 1 hour on 100% oxygen at sitting rest. Ascent to 40,000 feet (S.O.F.) and exercise. Cyanotic and coughing and pain in joints at 40,000 feet (S.O.F.). Pain disappeared on descent to 33,000 feet. From 35,000 feet to 40,000 feet for 2 hours. Had difficulty with intestinal gas since 15,000 feet was attained. Some gas in stomach or transverse colon with slight upper abdominal cramps. Better when sitting upright. After 1 hour and 27 minutes above 35,000 feet abdominal discomfort gone.

Flight 37, Dec. 5, 1939 Denitrogenated with exercise.
Denitrogenated by walking on treadmill at rate of 4 miles per hour breathing 100% oxygen for 25 minutes. This is the first time exercise was taken while denitrogenating on 100% oxygen. Because of slight symptoms of bends in Flight 35 after 1 hour denitrogenation at sitting rest it seemed advisable to test the value of exercise in order to shorten the time needed to eliminate sufficient nitrogen to prevent bends.

MAYO AERO MEDICAL UNIT

ASCENTS IN LOW PRESSURE CHAMBER

A few selected experiments which at the time done were considered
Record Events

7-27-39 Rochester	Experimental Subjects	W.R.Lovelace and pilot from Northwest Airlines.
	Denitrogenation	40 minutes on 100% oxygen at sitting rest.
	Ascent	From 1,000 ft. to 40,000 ft. (at 40,000 ft. for 2 minutes).
11-28-39 Rochester	Experimental Subjects	W.R.Lovelace and O.O.Benson.
	Denitrogenation	1 hour on 100% oxygen at sitting rest.
	Ascent	1,000 ft. to 40,000 ft. (at 40,000 ft. for 3 minutes).
1-14-40 Rochester	Experimental Subjects	Prof. C.E.Hall, Toronto and W.R. Lovelace.
	Denitrogenation.	25 minutes on 100% oxygen - Treadmill 2 miles per hour.
	Ascent	1,000 ft. to 40,000 ft. (at 40,000 ft. for 10 minutes).
6-12-40 Seattle	Experimental Subject	W.R.Lovelace
	Denitrogenation	30 minutes on 100% oxygen.
	Ascent	From sea level to 33,000 ft. in 11 minutes.
	Meeting, Seattle Branch, Institute of Aeronautical Sciences.	
6-26-40 Pasadena	Experimental Subject	W.R.Lovelace
	Denitrogenation.	On 100% oxygen preliminary to flight.
	Ascent	From sea level to 40,000 ft. in 8 minutes and 58 seconds.
	Meeting at Caltech of Institute of Aeronautical Sciences.	
8-31-40 Rochester	Experimental Subject	W.R.Lovelace
	Denitrogenation.	On 100% oxygen preliminary to flight.
	Ascent	1,000 ft. to 41,000 ft.
	Special demonstration for Mr. Robert Hinckley, Assistant Secretary of Commerce for Aviation and Dr. Brimhall, Director of Research, Civil Aeronautics Authority.	
9-22-41 Rochester	Experimental Subjects.	D.B.Dill, Wright Field and J.Wilson.
	Denitrogenation.	30 minutes on 100% oxygen - Treadmill 3 miles per hour.
	Ascent	1,000 ft. to 40,000 ft.(at 40,000 ft. for 25 minutes.)
10-3-41 Rochester	Experimental Subjects.	A.P.Gagge and H.Cranston.
	Denitrogenation.	36 minutes on 100% oxygen - Treadmill 3 miles per hour.
	Ascent	1,000 ft. to 42,200 ft. (40-42,200 ft. for 1 hour.)

ASCENTS IN LOW PRESSURE CHAMBER (Continued)

10-21-41 Rochester	Experimental Subjects	D.B.Dill, Wright Field and J.Resch.
	Dentrogonation	31 minutes on 100% oxygen - Treadmill 3 miles per hour.
	Ascent	1,000 ft. to 41,900 ft. (at 40-41,900 ft. for 2 hours and 40 minutes).
12-6-41 Rochester	Experimental Subjects	F.B.Vose, Sperry Gyro and Capt. Halbouty
	Denitrogenation	30 minutes on 100% oxygen - Treadmill 3 miles per hour.
	Ascent	1,000 ft. to 45,000 ft. (at 40-45,000 ft for 9 minutes)
1-15-42 Rochester	Experimental Subjects	J.W.Brown and L.A.Bullard.
	Denitrogonation	30 minutes on 100% oxygen - Treadmill 3 miles per hour.
	Ascent	1,000 ft. to 45,000 ft. (at 40-45,000 ft. for 10 minutes).
3-31-42 Rochester	Experimental Subjects	L. Cronin and Lt. Gressley.
	Denitrogenation	20 minutes on 100% oxygen - Treadmill 3 miles per hour.
	Ascent	1,000 ft. to 45,000 ft. (at 40-45,000 ft. for 57 minutes).

MAYO AERO MEDICAL UNIT

RAPID DESCENTS IN LOW PRESSURE CHAMBER

DATE		HIGHEST ELEVATION	TIME IN MINUTES AND SECONDS
10-3-42	C.A. Lindbergh L. Cronin	40,000 ft. to ground	36 seconds
1-7-43	J.P. Marbarger	45,000 ft. to ground	1 minute 10 seconds
1-8-43	J.P. Marbarger	50,608 ft. to ground	1 minute 15 seconds

MAYO AERO MEDICAL UNIT

SIMULATED PARACHUTE JUMPS TESTING VALUE OF BAIL-OUT BOTTLE

A few selected experiments which at the time done were considered Record Events

4-5-40 W.R. Lovelace and O.O. Benson denitrogenized for 33 minutes on 100% oxygen walking on treadmill and ascended to 35,000 ft. Lovelace simulated parachute jump from 35,000 ft. on bail-out bottle.

4-19-40 O.O. Benson and J.H. Doolittle denitrogenized for 35 minutes on 100% oxygen walking on treadmill and ascended to 40,000 ft. Benson simulated parachute jump from 35,000 ft. on bail-out bottle.

10-18-40 Milo Burcham, test pilot for Lockheed, Capt. Disoway and H. Smedal denitrogenized for 31 minutes on 100% oxygen walking on treadmill and ascended to 40,000 ft. Burcham simulated parachute jump from 35,000 ft. on bail-out bottle.

10-20-40 Milo Burcham and W.R. Lovelace denitrogenized for 59 minutes on 100% oxygen walking on treadmill and ascended to 35,000 ft. Violent exercise on bail-out bottle for 1 minute to imitate struggle to abandon plane. Burcham simulated parachute jump from 35,000 ft. Became unconscious at about 25,000 ft. Mask with oxygen applied by Lovelace.

12-17-42 A.R. Loomis, Willow Run and H. Cranston (movies) denitrogenized for 20 minutes on 100% oxygen walking on treadmill and ascended to 40,000 ft. Loomis simulated parachute jump from 40,000 ft. on bail-out bottle.

4-29-43 Murray Hawley, Willow Run, wearing old positive pressure vest and Heidbrink anesthesia mask, and J. P. Marbarger, wearing positive pressure vest and mask, denitrogenized for 15 minutes on 100% oxygen walking on treadmill and ascended to 50,000 ft. (at 40,000-50,000 ft. for 22 minutes). Hawley simulated parachute jump from 40,000 ft. on bail-out bottle.

MAYO AERO MEDICAL UNIT

RECORD ASCENTS IN LOW PRESSURE CHAMBER WITH POSITIVE PRESSURE

1-3-42 Norvin Erickson and Bill McFarland wearing Akerman positive pressure suit denitrogenized for 1 hour and 12 minutes on 100% oxygen walking on treadmill. Ascended to 44,000 ft. and stayed at 40,000-44,000 ft. for 10 minutes.

10-23-42 W.R. Lovelace wearing positive pressure mask without counter-pressure denitrogenized on 100% oxygen from ground up. Above 45,000 ft. for 7 minutes. Upon reaching 51,440 ft. suddenly became extremely cyanotic, collapsed and had convulsions Rapid descent to about 35,000 ft. when L. Cronin entered chamber from air lock, Lovelace recovered.

L. Cronin on positive pressure apparatus with weighted spirometer, no counter-pressure. She had denitrogenized on 100% oxygen intermittently for 16 hours. She ascended to 46,200 ft. and stayed there 11 minutes, then went into air lock which was lowered somewhat and changed to standard oxygen mask to observe W.R. Lovelace as he ascended to 51,440 ft. When he collapsed she entered main chamber upon equilization of pressures around 35,000 ft.

3-6-43 J.P. Marbarger and C.B. Taylor wearing pressure mask and a counter-pressure vest (laboratory model) using closed circuit principle with absorption of CO_2.

Arterial puncture made at 50,000 ft. Movie to show the technic and coordination of operator (16 minutes at 50,000 ft.)

Upon reaching 50,000 ft. arterial puncture easily and quickly made by Marbarger into the femoral artery of Taylor lying on cot. Three blood samples were taken after 1, 5 and 16 minutes at altitude. Movies taken almost continuously throughout stay at 50,000 ft. show operator perfectly coordinated and able to make the arterial puncture and move about in the chamber. The subject indicated condition throughout as excellent by regularly lifting right arm.

4-1-43 W. Burrows using Wright Field positive pressure regulator and J.P. Marbarger wearing positive pressure vest and mask denitrogenized for 20 minutes on 100% oxygen walking on treadmill. Ascended to 46,000 ft. and remained there for 27 minutes.

5-6-43 J.P. Marbarger wearing positive pressure mask connected to positive pressure regulator and Prof. Akerman's pressure suit and helmet (Navy) 2-2½ lbs. pressure. Ascended to 56,964 ft. and stayed there for 10 minutes, above 50,000 ft. for 16 minutes.

5-7-43 Ray Moore wearing Prof. Akerman's positive pressure suit and helmet with chin type mask. Ascended to 53,861 ft. and stayed above 52,000 ft. for 27 minutes.

5-8-43 Harley Thorson wearing Akerman suit and helmet denitrogenized on on 100% oxygen. Ascended to 57,165 ft. and stayed above 50,000 ft. for 35 minutes.

8-26-43 Capt. Dawbarn from Wright Field wearing Goodrich pressure suit. No denitrogenation because pressure maintained subject at low level. Ascended to 67,471 ft. and stayed for 5 minutes.

9-29-43 Phil Gilmore from Republic and H. F. Helmholz, Jr., wearing pressure mask with counter-pressure vest. Ascended to 47,473 ft. and stayed above 45,000 ft. for 4 minutes.

MAYO AERO MEDICAL UNIT

DATA FROM HIGH ALTITUDE LABORATORY

The data obtained by the research workers in the High Altitude Laboratory were usually best presented in charts. The majority of these charts were incorporated in the various reprints or papers listed in the bibliography.

It is time consuming to search through papers for the specific data they contain and as most of this data is valuable it seemed best for the convenience of any one reviewing the subject to have as much data as possible conveniently available. The graphs are self explanatory and are arranged in the following subject groups.

Group	I	Alveolar air data
Group	II	(a) Effect of altitude on oxygen pressure in the lung; (b) oxygen requirement at altitude.
Group	III	Percent saturation hemoglobin determined by (a) Van Slyke blood gas analysis (b) oximeter (c) from alveolar pO_2
Group	IV	Vital capacity.
Group	V	Voluntary hyperventilation.
Group	VI	Nitrogen elimination and effect of preoxygenation.
Group	VII	Effusion time of gases and their flow characteristics through single orifices and through sponge rubber disks.
Group	VIII	Miscellaneous.

MAYO AERO MEDICAL UNIT

DATA FROM HIGH ALTITUDE LABORATORY

Group I

ALVEOLAR AIR DATA

(1) II-1 August 1939, W.M.Boothby, B.A.McSwiney and A.Uihlein.
Alveolar pO_2 resulting from increasing rate of oxygen flow using a BLB mask on a small, medium and large individual at ground level.

(2) II-2 November 1940, W.M.Boothby, J.Pratt and H.Smedal.
Alveolar oxygen and CO_2 pressures as affected by varying (1) size of reservoir bag of BLB mask and (2) rate of oxygen flow at ground level.

(3) II-3 August 1940 W.M.Boothby and W.R.Lovelace
Alveolar oxygen pressures as effected by different rates of oxygen flow using different methods of administration at ground level.

(4) I-1 September 1940, W.M.Boothby, W.R.Lovelace and O.O.Benson Jr.
Alveolar O_2 pressures at increasing altitude (a) while breathing air and (b) while adding oxygen at indicated rates of flow per minute as recommended to maintain normal tracheal pO_2.

(5) I-2 September 1940, W.M.Boothby, W.R.Lovelace and O.O.Benson Jr.
Alveolar O_2 and CO_2 pressures at various altitudes breathing air in low pressure chamber compared with data obtained by McFarland in nitrogen chamber (method of calculating altitude not known)

(6) I-3 November 1940, W.M.Boothby, N. Erickson, H. Smedal and J.Pratt.
No significant difference in the alveolar O_2 and CO_2 pressures at various altitudes found on subjects with and without breakfast.

(7) I-4 September 1940, W.M.Boothby and W.B.Dublin.
Effect of regulated hyperventilation on alveolar O_2 and CO_2 pressures at various altitudes.

(8) I-5a 1940 revised 1943 by W.M.Boothby.
Alveolar O_2 and CO_2 pressures while breathing oxygen at stipulated rates of flow using BLB mask at elevations up to 42,000 feet.

(9) I-6b October 1943, W.M.Boothby
1313 alveolar pO_2 and pCO_2 individual observations and their averages at various altitudes in low pressure chamber.

(10) I-7 September 1943, W.M.Boothby
The same alveolar oxygen pressure is attained by simulating altitude by addition of nitrogen as found in previous experiments in low pressure chamber.

(11) I-6b-c August 1944, J.W.Wilson and W.M.Boothby
Alveolar air data on subjects acclimatized to 6,180 feet at Peterson Field Colorado Springs Colorado. Cooperative study Wright Field Aero Medical Laboratory and Mayo Aero Medical Unit.

Alveolar Air Data (continued)

(12) I-6b-1 August 1944, J.W.Wilson and W.M.Boothby.
Alveolar air data on same four subjects
(a) At Rochester, altitude 1,000 feet.
(b) After 2 or 3 days at Colorado Springs, altitude 6,180 feet.
(c) After 2 weeks at Colorado Springs.

(13) I-6E February 1944, W.M.Boothby.
Comparison alveolar air data in males and females at various altitudes.

(14) I-10a March 1942, W.M.Boothby.
Alveolar pO2 and pCO2 and alveolar pressure ratios as affected by duration of stay at 15,000 feet. (Stabilization within 15 minutes after removal normal oxygen.)

(15) I-10b July 1943, W.M.Boothby and H.F.Helmholz Jr.
Alveolar pO2, pCO2 and APR as affected by duration of stay at 10,000 feet (immediate stabilization.)

(16) I-10c June 1944, W.M.Boothby and J.B.Bateman.
Alveolar pO2, pCO2 and APR as affected by duration of stay at 15,000 feet (no oxygen during ascent 3 minutes).

(17) XII-7a May 1942, W.M.Boothby.
240 observations on pO2, pCO2 at various atmospheric pressures from 270 mm. to 350 mm.

(18) I-11a June 1944, J.B.Bateman and W.M.Boothby
Comparison of respiratory quotients calculated from analyses of alveolar and total expired air.

(19) I-11b June 1944, J.B. Bateman.
Time course of change of true respiratory quotient and alveolar respiratory quotient after a meal of rice at ground level of 1,000 ft.

(20) I-11c June 1944, J.B.Bateman.
Same as (19) except experiment done at 12,000 ft.

(21) I-11e June 1944, J.B.Bateman.
Comparison of observed changes in partial pressures with those calculated from changes in respiratory quotient occurring after meal of rice.

(22) I-6d-b June 1944, W.M.Boothby
Comparison of inspired, tracheal and alveolar air pressure between low altitudes breathing air and high altitudes breathing oxygen. (chart available in large size for indoctrination).

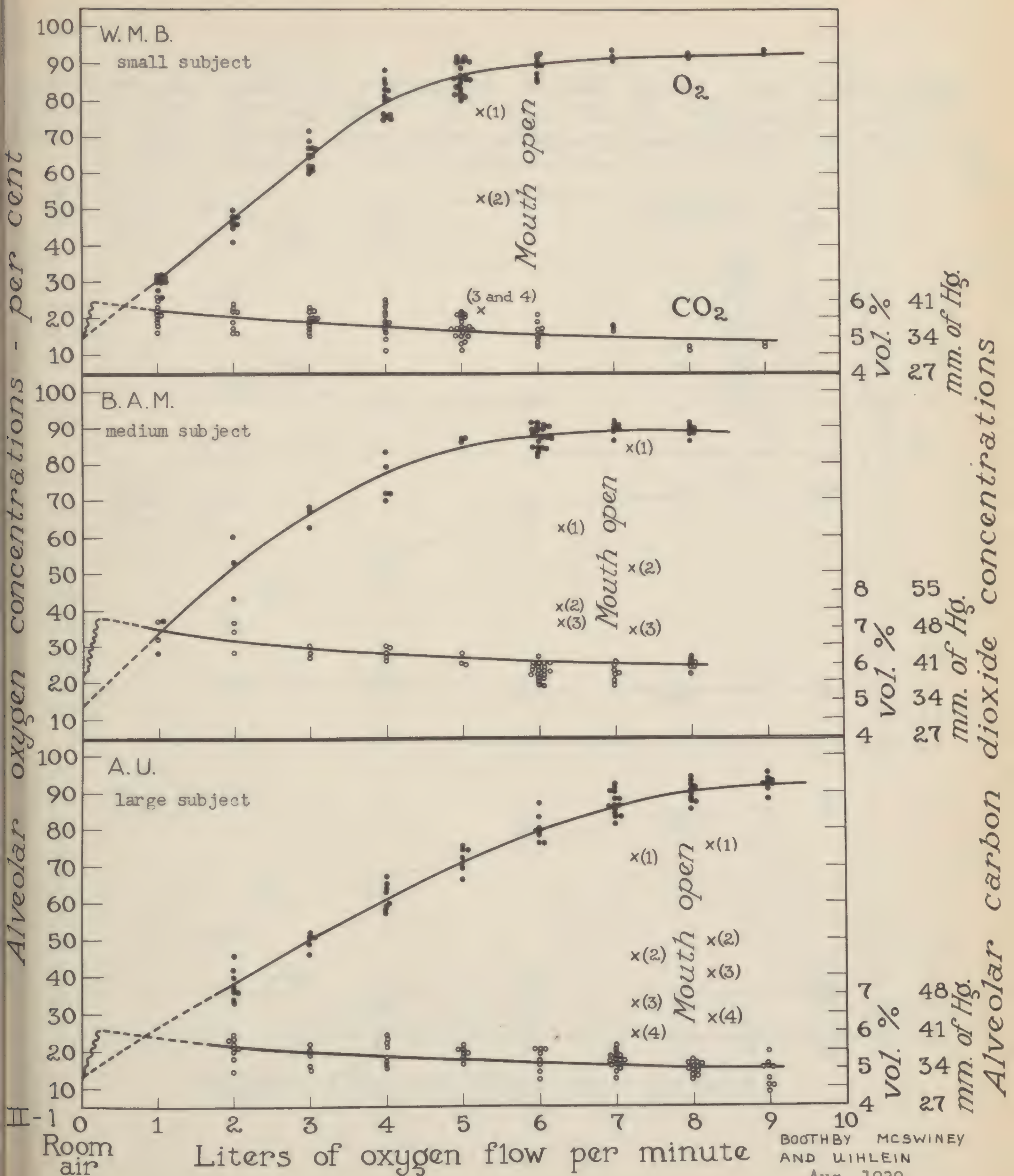
(23) I-6d-c June 1944, W.M.Boothby, H.F.Helmholz Jr. and J.B.Bateman
Effect of anoxia on alveolar air pressure: A simplified form of (22) for indoctrination.

Alveolar air data (continued.)

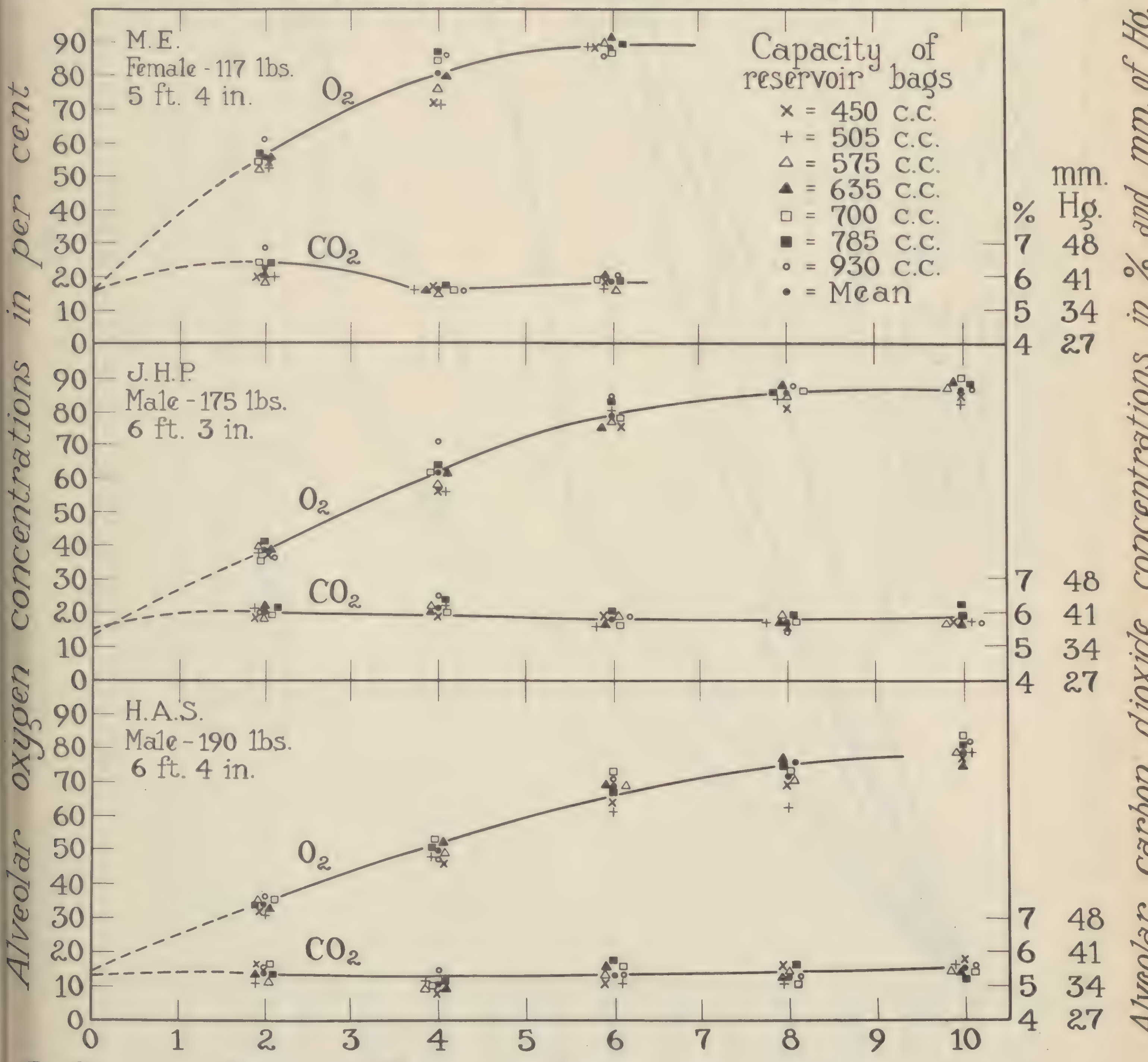
(24) I-6d-a August 1940, W.M.Boothby, H.F.Helmholz Jr. and J.B.Bateman
Atmospheric Triangles: Another simple form of (22) for indoctrination.

(25) I-6b-2 December 1945 , H.F.Helmholz and W.M.Boothby
Changes in APR and ARQ (1) after ascending to 18,000 feet for 1 hour and (2) after descending to ground for 1 hour.

Alveolar oxygen pressures with various rates of flow of oxygen using B.L.B. mask



ALVEOLAR O_2 AND CO_2 PRESSURES IN ONE SMALL AND TWO LARGE SUBJECTS AT SITTING REST AS AFFECTED BY VARYING (1) SIZE OF BAG OF BLB OXYGEN INHALATION APPARATUS AND (2) RATE OF O_2 FLOW



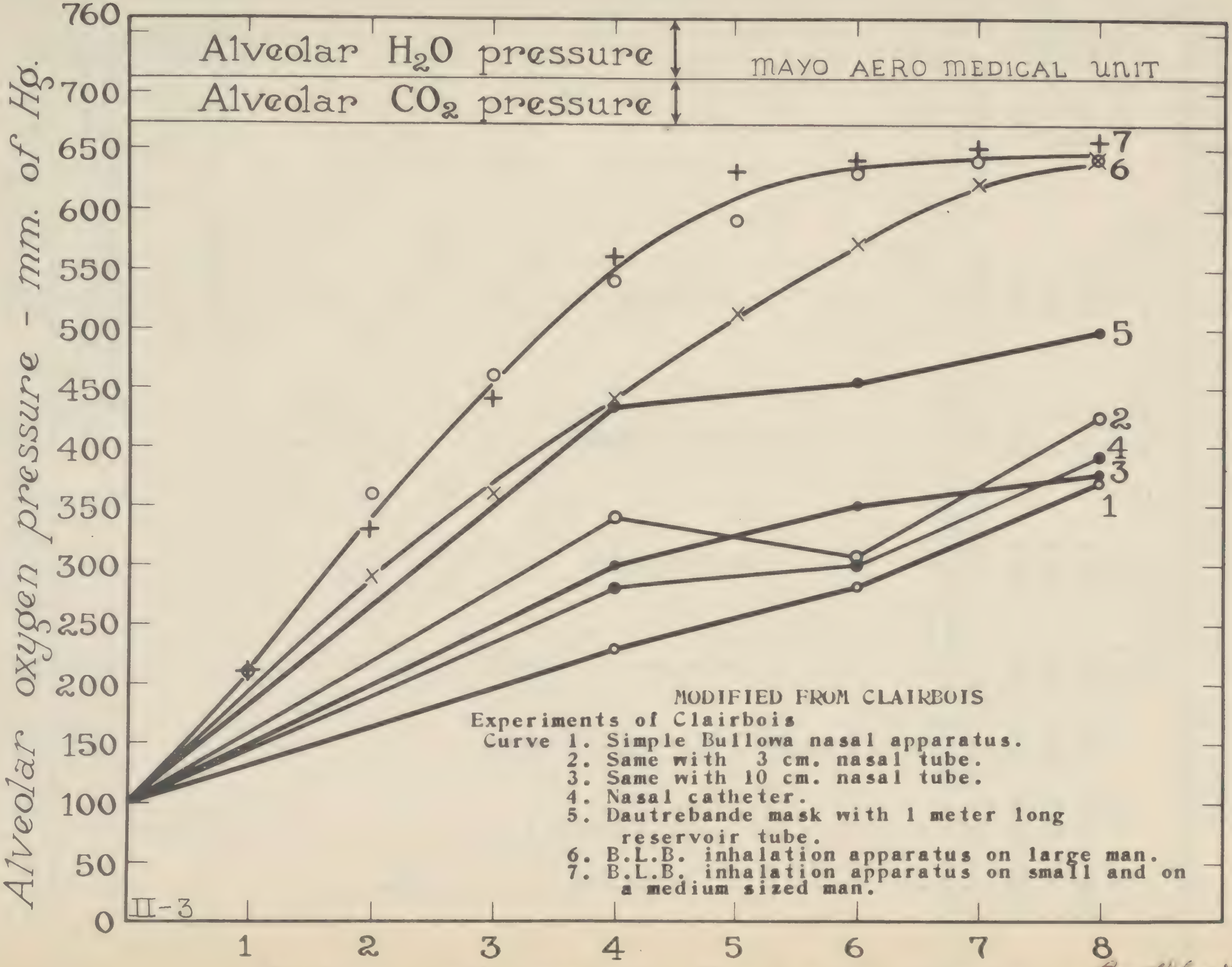
II-2

BOOTHBY PRATT AND SMEDAL

(2)

Nov. 1940

Alveolar Oxygen Pressures as effected by different Rates and different Method of Oxygen Flow

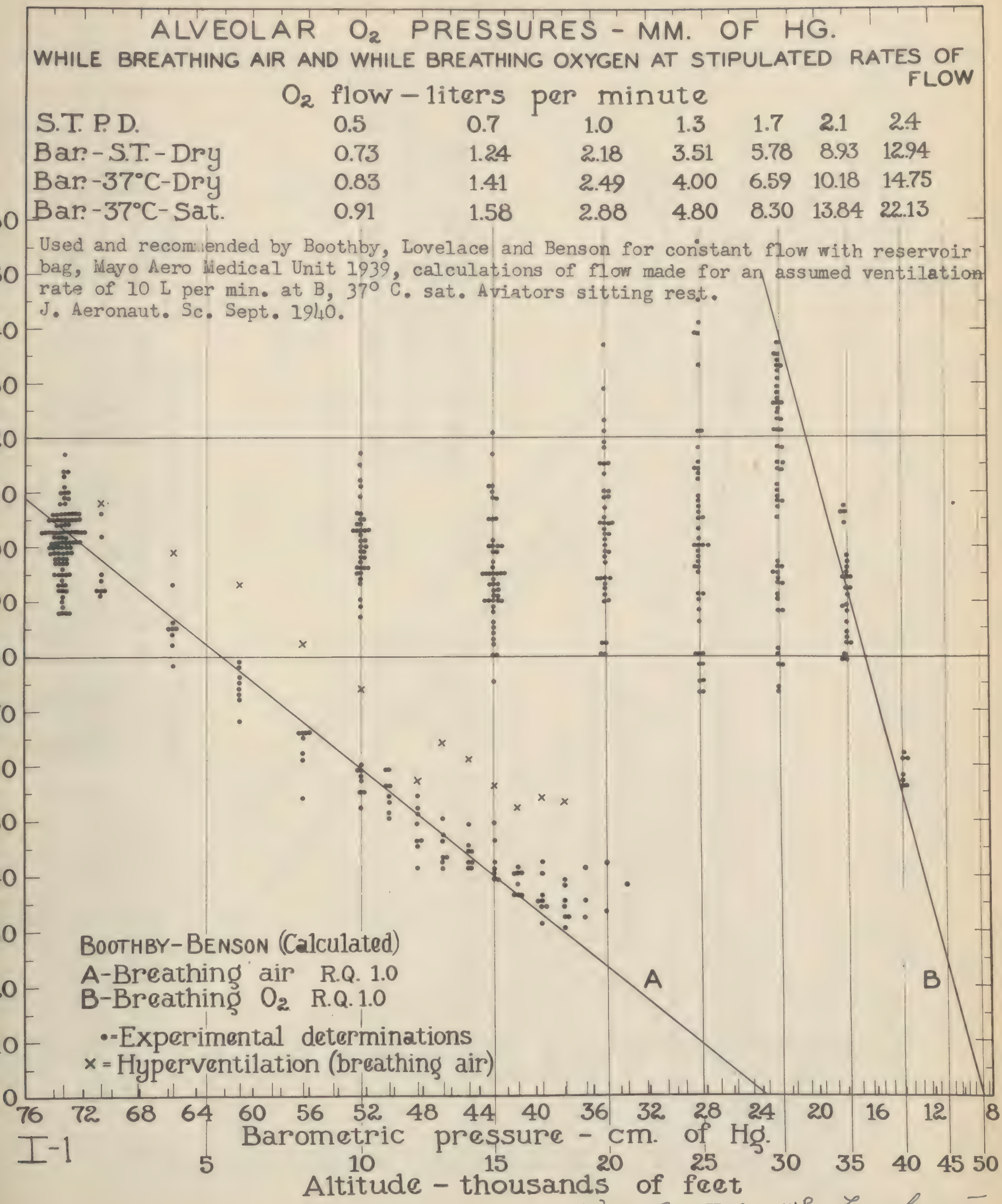


Boothby & Lovelace
Aug. 1940

(3)

Subject: High altitude effect on human body
Published: J. Aeronaut. Sc. 7: 465, Sept. 1940.

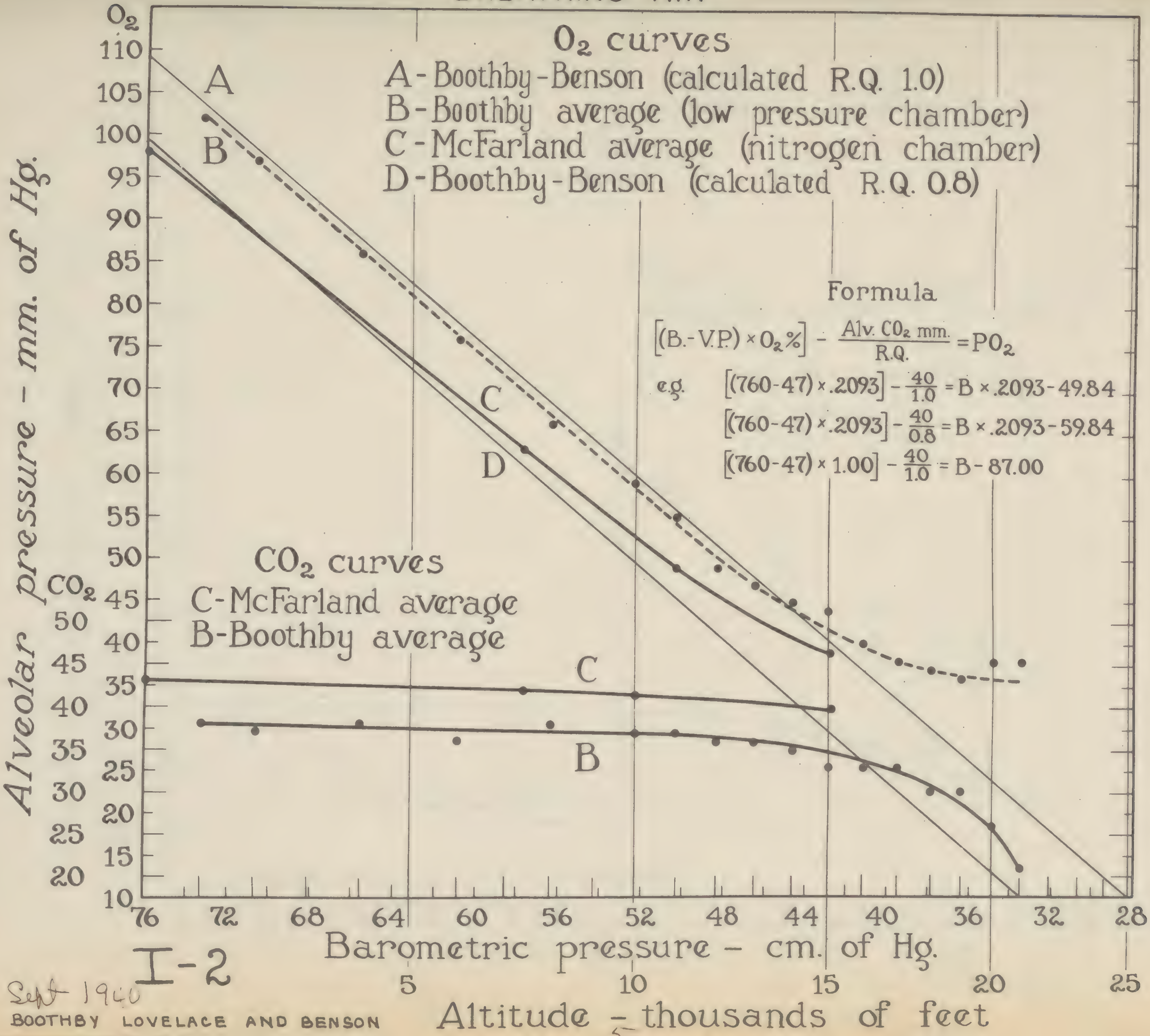
EQUIVALENT ALTITUDES



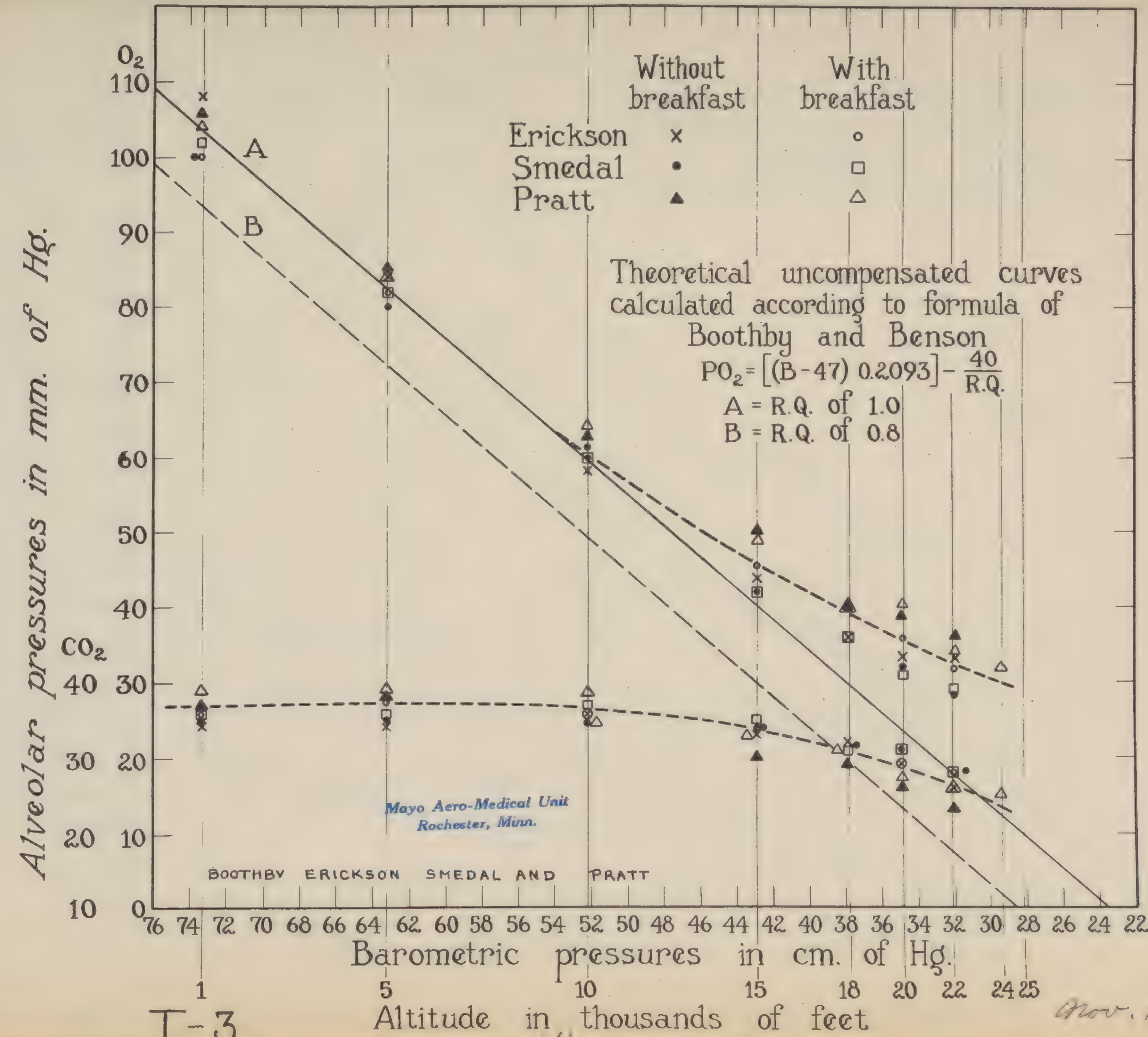
I-1

Wm. Boothby, W.R. Lovelace II,
O.A. Benson Jr.
Sept. 1940

ALVEOLAR O_2 AND CO_2 PRESSURES AT VARIOUS ALTITUDES - BREATHING AIR



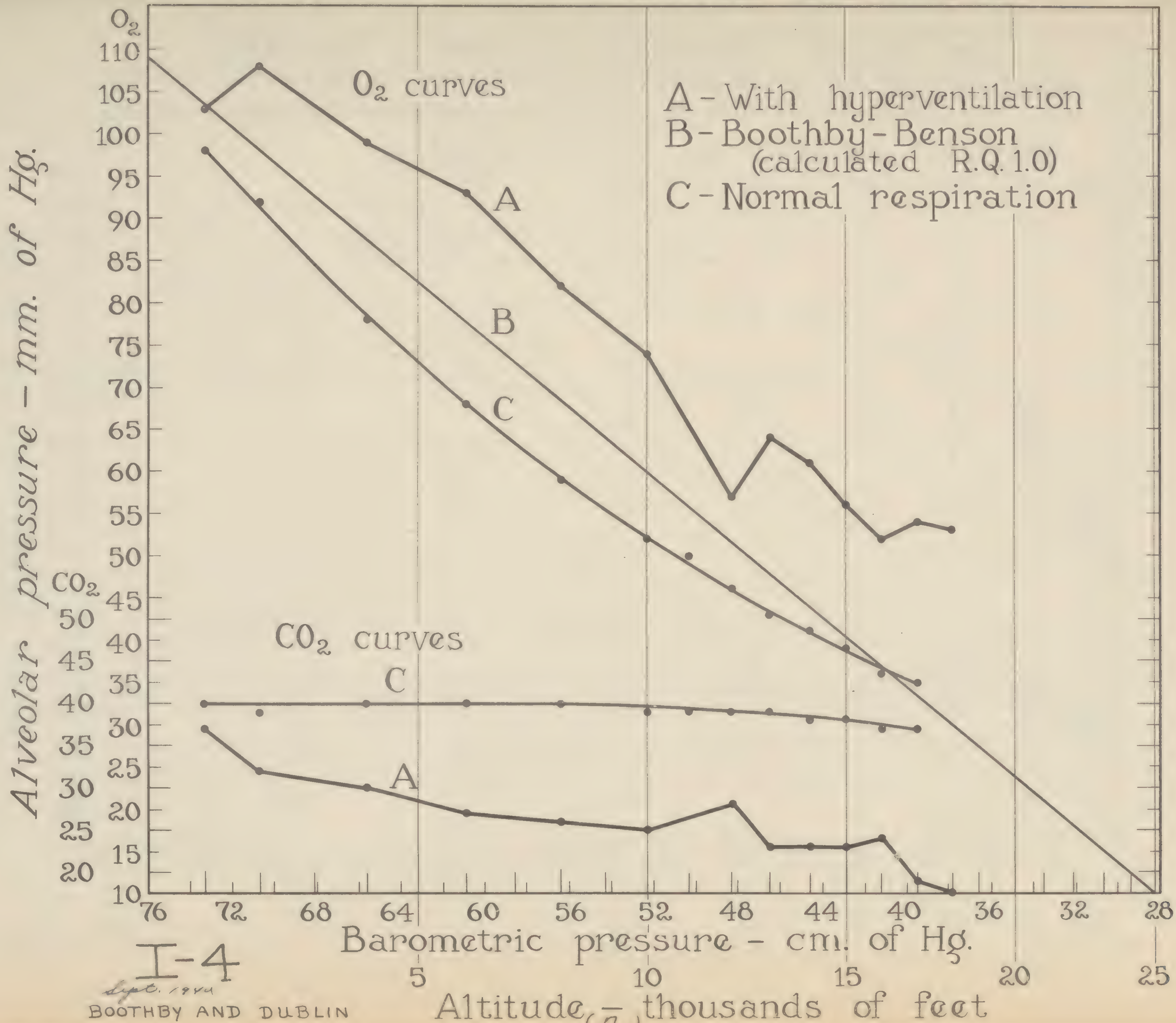
ALVEOLAR O_2 AND CO_2 PRESSURES AT VARIOUS ALTITUDES - BREATHING AIR - BEFORE AND AFTER BREAKFAST



I-3

Nov. 1940

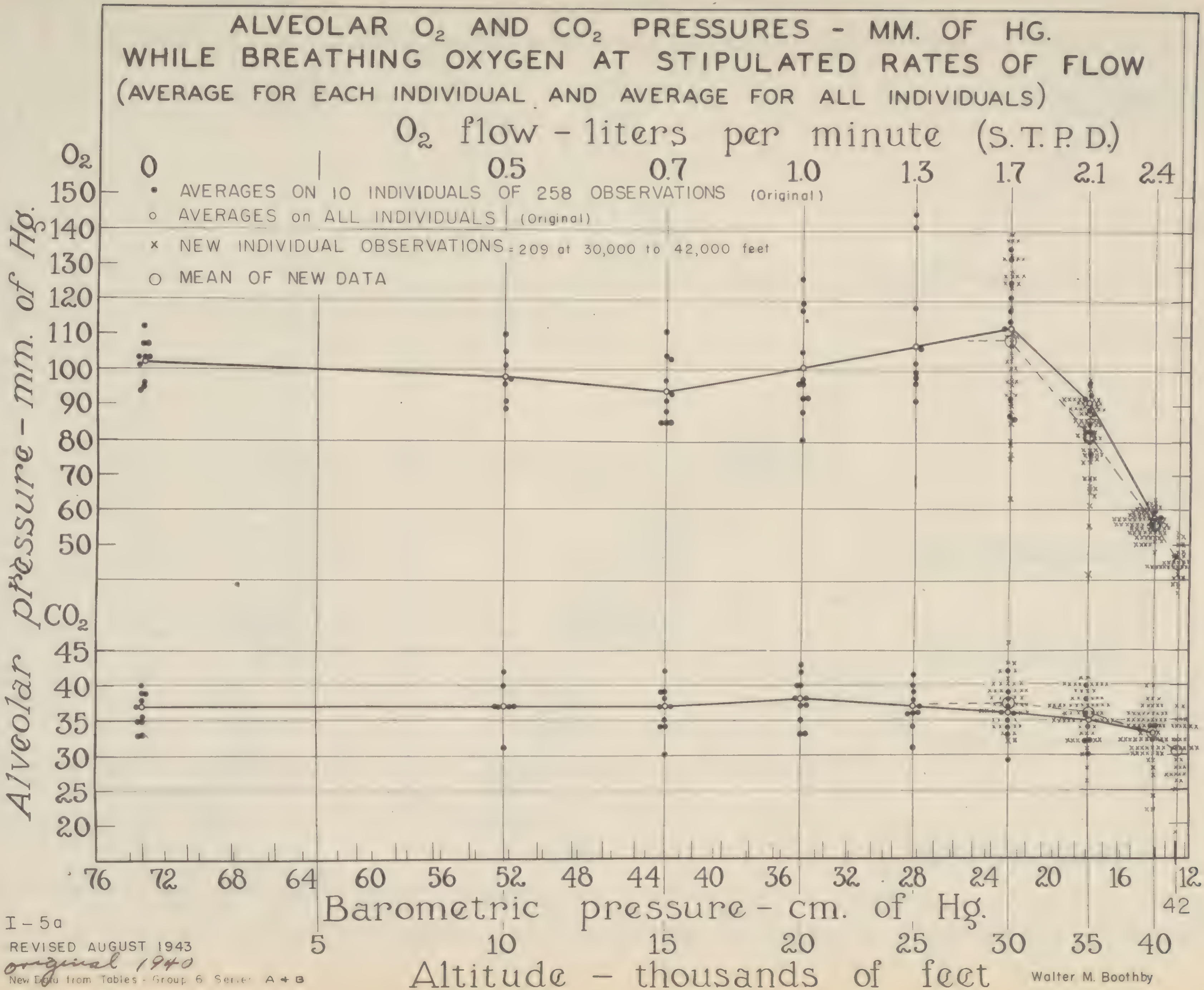
THE EFFECT OF HYPERVENTILATION ON ALVEOLAR O_2 AND CO_2 PRESSURES AT VARIOUS ALTITUDES - BREATHING AIR



I-4

Sept. 1944

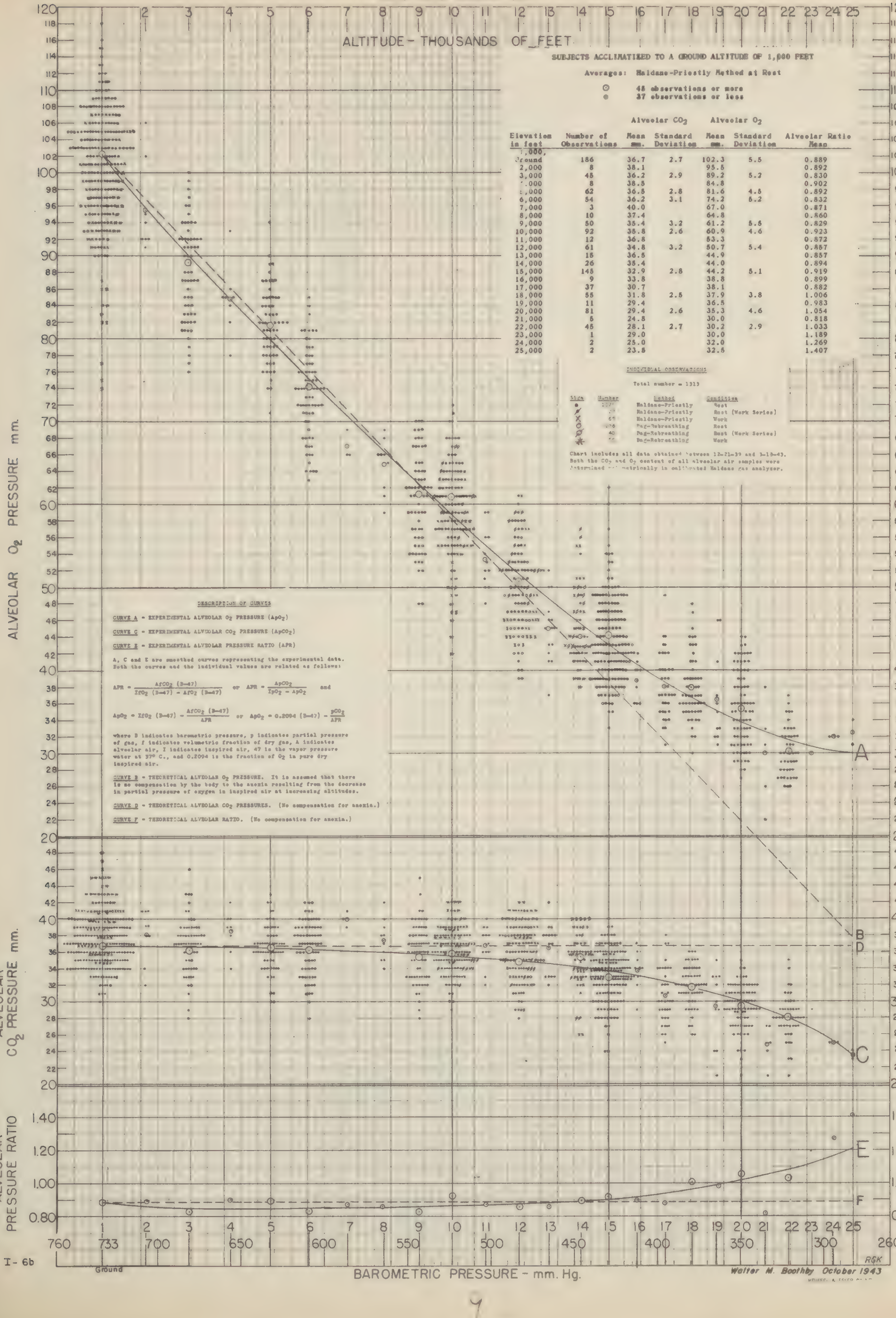
BOOTHBY AND DUBLIN



I - 5a
REVISED AUGUST 1943
original 1940
New Data from Tables - Group 6 Series A + B

ALVEOLAR O_2 and CO_2 PRESSURES and ALVEOLAR RATIOS at VARIOUS ALTITUDES WHILE BREATHING AIR

MAYO AERO MEDICAL UNIT



SUBJECTS ACCLIMATIZED TO A GROUND ALTITUDE OF 1,000 FEET

Averages: Haldane-Priestly Method at Rest

⊙ 45 observations or more
● 37 observations or less

Elevation in feet	Number of Observations	Alveolar CO_2 Mean mm.	Alveolar CO_2 Standard Deviation	Alveolar O_2 Mean mm.	Alveolar O_2 Standard Deviation	Alveolar Ratio Mean
1,000, Ground	186	36.7	2.7	102.3	5.5	0.889
2,000	8	38.1		95.5		0.892
3,000	45	36.2	2.9	89.2	5.2	0.830
4,000	8	38.5		84.8		0.902
5,000	62	36.5	2.8	81.6	4.5	0.892
6,000	54	36.2	3.1	74.2	5.2	0.832
7,000	3	40.0		67.0		0.871
8,000	10	37.4		64.8		0.860
9,000	50	35.4	3.2	61.2	5.5	0.829
10,000	92	35.8	2.6	60.9	4.6	0.923
11,000	12	36.8		53.3		0.872
12,000	61	34.8	3.2	50.7	5.4	0.857
13,000	15	36.5		44.9		0.857
14,000	26	35.4		44.0		0.894
15,000	145	32.9	2.8	44.2	5.1	0.919
16,000	9	33.8		38.8		0.899
17,000	37	30.7		38.1		0.882
18,000	55	31.8	2.5	37.9	3.8	1.006
19,000	11	29.4		36.5		0.983
20,000	81	29.4	2.6	35.3	4.6	1.054
21,000	5	24.8		30.0		0.818
22,000	45	28.1	2.7	30.2	2.9	1.033
23,000	1	29.0		30.0		1.189
24,000	2	25.0		32.0		1.269
25,000	2	23.5		32.5		1.407

INDIVIDUAL OBSERVATIONS

Total number = 1313

Sign	Number	Method	Condition
●	[illegible]	Haldane-Priestly	Rest
⌀	[illegible]	Haldane-Priestly	Rest (Work Series)
×	[illegible]	Haldane-Priestly	Work
○	[illegible]	Bag-Rebreathing	Rest
⌀	40	Bag-Rebreathing	Rest (Work Series)
✱	[illegible]	Bag-Rebreathing	Work

Chart includes all data obtained between 12-21-39 and 3-13-43. Both the CO_2 and O_2 content of all alveolar air samples were determined volumetrically in calibrated Haldane gas analyzer.

DESCRIPTION OF CURVES

CURVE A - EXPERIMENTAL ALVEOLAR O_2 PRESSURE (ApO_2)

CURVE C - EXPERIMENTAL ALVEOLAR CO_2 PRESSURE ($ApCO_2$)

CURVE E - EXPERIMENTAL ALVEOLAR PRESSURE RATIO (APR)

A, C and E are smoothed curves representing the experimental data. Both the curves and the individual values are related as follows:

$$APR = \frac{AfCO_2\,(B-47)}{IfO_2\,(B-47) - AfO_2\,(B-47)} \quad \text{or} \quad APR = \frac{ApCO_2}{IpO_2 - ApO_2} \quad \text{and}$$

$$ApO_2 = IfO_2\,(B-47) - \frac{AfCO_2\,(B-47)}{APR} \quad \text{or} \quad ApO_2 = 0.2094\,(B-47) - \frac{pCO_2}{APR}$$

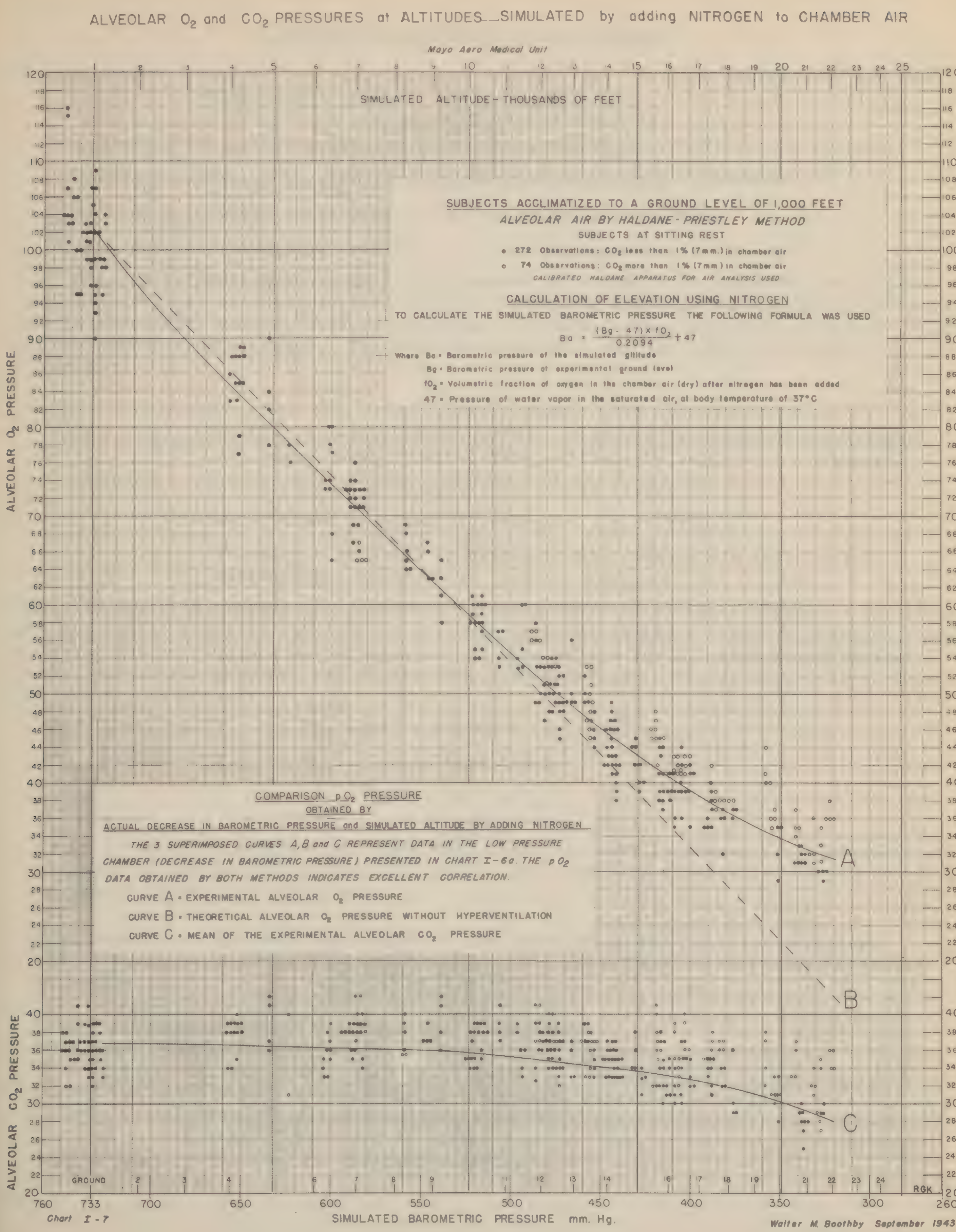
where B indicates barometric pressure, p indicates partial pressure of gas, f indicates volumetric fraction of dry gas, A indicates alveolar air, I indicates inspired air, 47 is the vapor pressure water at 37° C., and 0.2094 is the fraction of O_2 in pure dry inspired air.

CURVE B - THEORETICAL ALVEOLAR O_2 PRESSURE. It is assumed that there is no compensation by the body to the anoxia resulting from the decrease in partial pressure of oxygen in inspired air at increasing altitudes.

CURVE D - THEORETICAL ALVEOLAR CO_2 PRESSURES. (No compensation for anoxia.)

CURVE F - THEORETICAL ALVEOLAR RATIO. (No compensation for anoxia.)

Based on comparison of tracheal nitrogen
Corresponds to comparison of tracheal as opposed to alveolar oxygen



CALCULATION ELEVATION USING NITROGEN

I. The partial pressure* of oxygen in the tracheal air** at any altitude is obtained from the following equation:

$$(P_{O2})_a = (B_a - 47) \times 0.2093$$

Where $(P_{O2})_a$ = partial pressure of oxygen in the tracheal air at any altitude.

B_a = total barometric pressure at the altitude

47 = water vapor pressure of saturated air at 37°C.

0.2093 = volumetric fraction of oxygen in atmospheric air (dry)

II. When it is impossible to go to the desired altitude or to simulate the altitude in a low pressure chamber, another method of studying effects of altitude on the aviator is available, namely, that of reducing in a chamber the partial pressure of oxygen by the addition of nitrogen. The altitude resulting thereby can be determined as follows:

$$(P_{O2})_g = (B_g - 47) \times f_{O2}$$

Where $(P_{O2})_g$ = partial pressure in mm. of Hg. of oxygen in tracheal air obtained at ground level by simulating altitude by addition of nitrogen.

B_g = total barometric pressure at ground level.

47 = water vapor pressure of saturated air at 37°C.

f_{O2} = volumetric fraction of oxygen in the chamber air (dry) after nitrogen has been added.

III. In order to compare the results obtained between an altitude simulated by nitrogen with those actually obtained by altitude or by utilizing a negative pressure chamber, the two expressions may be equated and then solved for B_a which would be the actual barometric pressure for an altitude corresponding to the nitrogen added. Equating the two equations:

$$(B_a - 47) \times 0.2093 = (B_g - 47) \times f_{O2}$$

solving for B_a

$$B_a = \frac{(B_g - 47) \times f_{O2}}{0.2093} + 47$$

It is to be noted specifically that this method in both instances deals properly and simply with the partial pressure of water vapor which is constant at 47 mm. of Hg. in the lungs under all conditions.

From barometric pressure thus obtained one looks up in the "Altitude-Pressure Tables Based on the United States Standard Atmosphere" the corresponding altitude in feet.

---

*All pressures expressed in millimeters of mercury.

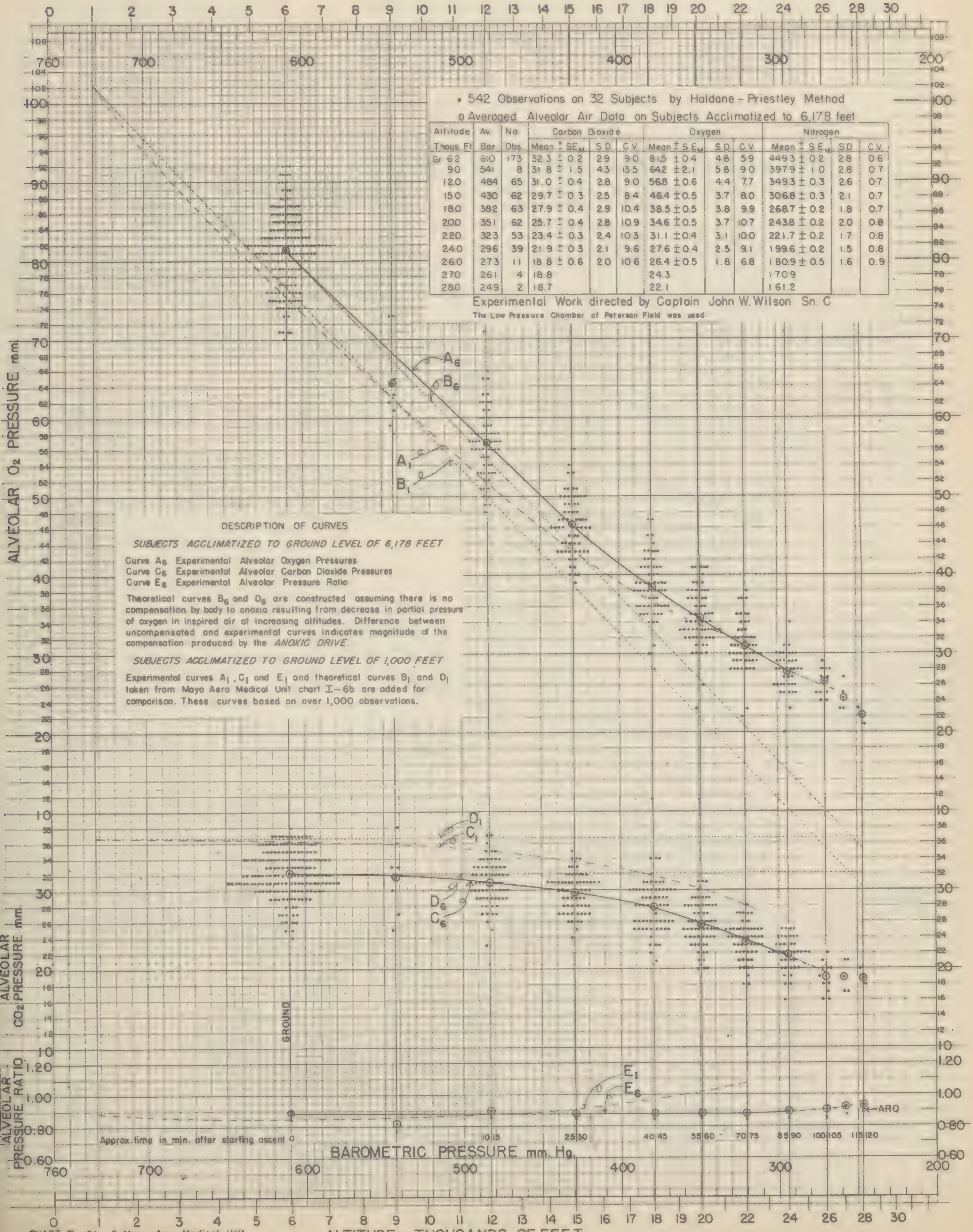
**The term "tracheal air" is used arbitrarily to indicate atmospheric air saturated with moisture at body temperature which is the actual condition of the air as it enters the alveoli before any exchange with blood gases has occurred. This is, of course, an arbitrary division because gas exchange proceeds more or less simultaneously with saturation. The word "trachea" does not have an anatomical limitation but, as mentioned above, is used arbitrarily.

ALVEOLAR O_2 AND CO_2 PRESSURES AND ALVEOLAR RATIOS AT VARIOUS ALTITUDES WHILE BREATHING AIR

A Cooperative Study carried out at Peterson Field, Colorado Springs, Colorado by

WRIGHT FIELD AERO MEDICAL LABORATORY AND MAYO AERO MEDICAL UNIT

SUBJECTS ACCLIMATIZED TO 6,180 FEET



• 542 Observations on 32 Subjects by Haldane - Priestley Method

o Averaged Alveolar Air Data on Subjects Acclimatized to 6,178 feet

Altitude	Av.	No.	Carbon Dioxide			Oxygen			Nitrogen		
Thous Ft	Bar	Obs	Mean $\pm$ SE_M	S D	C V	Mean $\pm$ SE_M	S D	C V	Mean $\pm$ SE_M	S D	C V
Gr 6 2	610	173	32 3 $\pm$ 0.2	2 9	9 0	81.5 $\pm$ 0 4	4 8	5 9	449 3 $\pm$ 0 2	2 8	0 6
9 0	541	8	31 8 $\pm$ 1.5	4.3	13 5	64.2 $\pm$ 2.1	5.8	9.0	397 9 $\pm$ 1 0	2.8	0 7
12.0	484	65	31.0 $\pm$ 0.4	2.8	9.0	56.8 $\pm$ 0.6	4.4	7.7	349.3 $\pm$ 0.3	2.6	0 7
15.0	430	62	29.7 $\pm$ 0.3	2.5	8 4	46.4 $\pm$ 0.5	3.7	8.0	306.8 $\pm$ 0.3	2.1	0.7
18.0	382	63	27.9 $\pm$ 0.4	2.9	10.4	38.5 $\pm$ 0.5	3.8	9.9	268.7 $\pm$ 0.2	1.8	0.7
20.0	351	62	25.7 $\pm$ 0.4	2.8	10.9	34.6 $\pm$ 0.5	3.7	10.7	243.8 $\pm$ 0.2	2.0	0.8
22.0	323	53	23.4 $\pm$ 0.3	2 4	10 3	31.1 $\pm$ 0.4	3.1	10.0	221.7 $\pm$ 0.2	1 7	0.8
24.0	296	39	21.9 $\pm$ 0 3	2.1	9.6	27.6 $\pm$ 0.4	2.5	9.1	199.6 $\pm$ 0.2	1.5	0.8
26.0	273	11	18 8 $\pm$ 0.6	2 0	10 6	26.4 $\pm$ 0.5	1.8	6.8	180.9 $\pm$ 0.5	1.6	0.9
27.0	261	4	18 8			24.3			170 9		
28.0	249	2	18.7			22.1			161.2		

Experimental Work directed by Captain John W. Wilson Sn. C

The Low Pressure Chamber of Peterson Field was used.

DESCRIPTION OF CURVES

SUBJECTS ACCLIMATIZED TO GROUND LEVEL OF 6,178 FEET

Curve A_6 Experimental Alveolar Oxygen Pressures
Curve C_6 Experimental Alveolar Carbon Dioxide Pressures
Curve E_6 Experimental Alveolar Pressure Ratio

Theoretical curves B_6 and D_6 are constructed assuming there is no compensation by body to anoxia resulting from decrease in partial pressure of oxygen in inspired air at increasing altitudes. Difference between uncompensated and experimental curves indicates magnitude of the compensation produced by the *ANOXIC DRIVE*.

SUBJECTS ACCLIMATIZED TO GROUND LEVEL OF 1,000 FEET

Experimental curves A_1, C_1 and E_1 and theoretical curves B_1 and D_1 taken from Mayo Aero Medical Unit chart I - 6b are added for comparison. These curves based on over 1,000 observations.

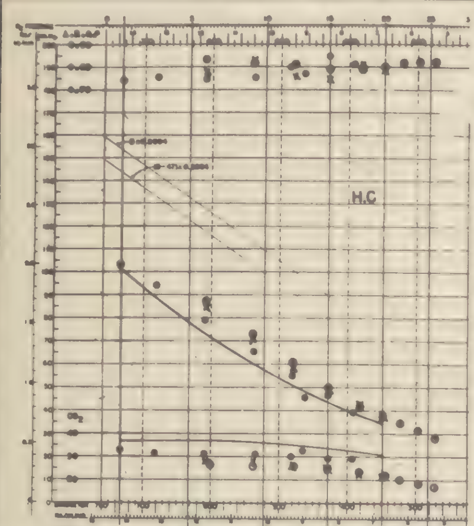
CHART I - 6b - C. Mayo Aero Medical Unit
Walter M. Boothby August 1944

Mayo Aero Medical Unit

ALVEOLAR O_2 AND CO_2 PRESSURES AND ALVEOLAR R.Q. BREATHING AIR

Data obtained at Colorado Springs (6,180 feet)
X Shortly after arrival (1 flight)
⊖ After two weeks (1 flight)

Data obtained previously at Rochester, Minnesota (1,000 feet)
● Average of several flights



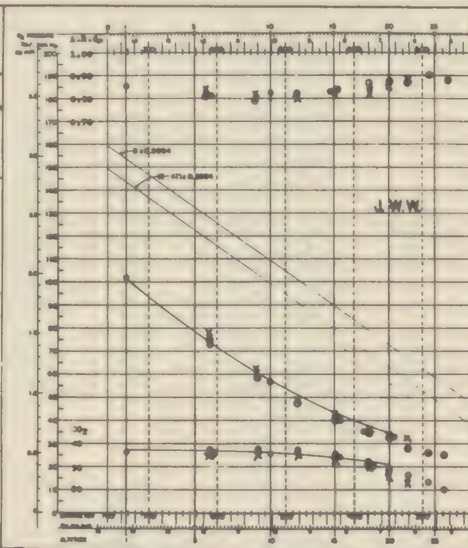
Subject H.C. at Colorado Springs, Peterson Field. (1 flight)
1 day at 6,180 feet. X

		Alveolar			Diff.	
		CO_2	O_2	N_2	$IpN_2 - ApN_2$	
Elev.	Bar.	mm.	mm.	mm.	mm.	A.R.Q.
6	609	28	84	490	+ 6	0.78
9	539	28	71	393	+ 4	0.83
12	479	26	50	347	+ 6	0.76
15	432	25	40	311	+ 7	0.75
18	382	23	43	269	+ 4	0.81
20	347	21	38	241	+ 4	0.78
13 days at 6,180 feet. (1 flight) ⊖						
6	611	27	88	449	+ 3	0.84
9	541	26	73	395	+ 5	0.82
12	483	26	61	349	+ 4	0.81
15	432	25	50	310	+ 6	0.79
18	382	23	42	270	+ 5	0.79
20	352	22	38	245	+ 4	0.80
22	323	20	35	221	+ 3	0.82
24	296	18	31	200	+ 3	0.82
26	272	17	28	180	+ 2	0.82

At 1,000 feet, Rochester, Minnesota.
Average of 4 flights. ●

1	733	33	103	550	+ 8	0.74
3	681	31	94	509	+ 8	0.76
6	609	31	79	452	+ 8	0.75
9	543	31	65	400	+ 8	0.76
12	483	30	55	351	+ 6	0.80
13	465	33	46	339	+ 9	0.77
15	429	29	47	306	+ 4	0.85
17	395	29	39	280	+ 5	0.81

Curve from chart I-6b



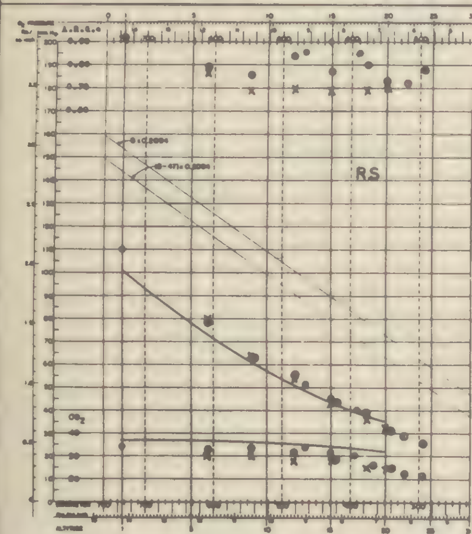
Subject Capt. J.W.W. Colorado Springs, Peterson Field, Elevation 6,180 feet.
1 day at 6,180 feet X (1 flight)

		CO_2	O_2	N_2	
Elev.	Bar.	mm.	mm.	mm.	A.R.Q.
6	609	35	76	449	0.84
9	539	35	62	398	0.82
12	479	35	49	348	0.80
15	432	32	43	310	0.82
18	382	30	36	270	0.82
20	347	26	34	241	0.85
22	321	23	32	219	0.88
14 days at 6,180 feet. ⊖ (1 flight)					
6	611	36	75	453	0.81
9	541	37	59	399	0.79
12	483	37	46	351	0.82
15	432	35	40	310	0.83
18	382	32	35	269	0.87
20	352	28	33	245	0.87
22	323	27	28	222	0.87
24	296	23	27	199	0.90
26	272	20	25	180	0.87

At 1,000 ft. Rochester, Minnesota.
1 flight. ●

1	728	37	101	543	0.86
6	608	37	73	451	0.81
10	522	36	57	381	0.82
15	430	34	40	308	0.82
18	380	30	35	268	0.85

Curve from chart I-6b

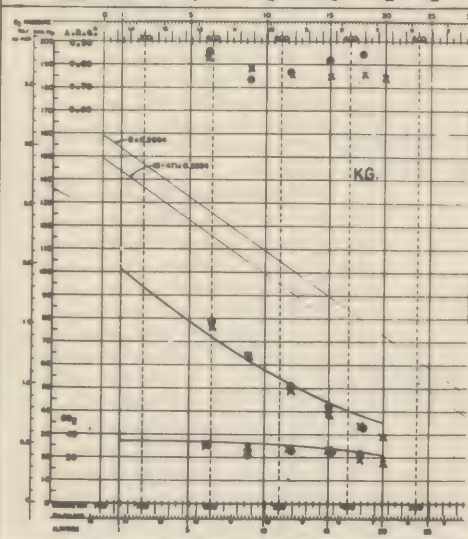


Subject R.S. Colorado Springs, Peterson Field. Elevation 6,180 ft.
2 days at 6,180 ft. X (1 flight)

		CO_2	O_2	N_2	
Elev.	Bar.	mm.	mm.	mm.	A.R.Q.
6	608	30	80	452	0.77
9	546	30	64	406	0.88
12	438	28	54	356	0.70
15	431	28	43	313	0.88
18	382	25	36	274	0.88
20	353	24	32	250	0.70
15 days at 6,180 ft. ⊖ (1 flight)					
6	613	33	79	455	0.79
9	540	33	63	398	0.76
12	480	31	56	347	0.84
15	427	29	43	307	0.77
18	380	26	39	268	0.80
20	346	25	31	244	0.73
22	321	22	29	224	0.72
24	294	21	26	200	0.78

At 1,000 ft. Rochester, Minnesota.
1 flight. ●

1	742	34	110	551	0.92
13	469	33	51	338	0.86
15	422	31	45	299	0.90
17	395	30	40	278	0.86



Subject K. G. Colorado Springs, Peterson Field. (1 flight)
2 days at 6,180 ft. X

		Alveolar			Diff.	
		CO_2	O_2	N_2	$IpN_2 - ApN_2$	
Elev.	Bar.	mm.	mm.	mm.	mm.	A.R.Q.
6	609	35	77	450	+ 6	0.82
9	499	34	63	402	+ 8	0.78
12	485	34	48	355	+ 9	0.76
15	431	33	39	312	+ 9	0.75
18	382	29	34	272	+ 7	0.78
20	353	27	29	250	+ 8	0.74
15 days at 6,180 ft. (1 flight) ⊖						
6	613	35	79	452	+ 5	0.85
9	540	31	63	399	+ 9	0.73
12	480	33	51	350	+ 8	0.77
15	427	32	42	307	+ 7	0.82
18	380	32	32	268	+ 5	0.84

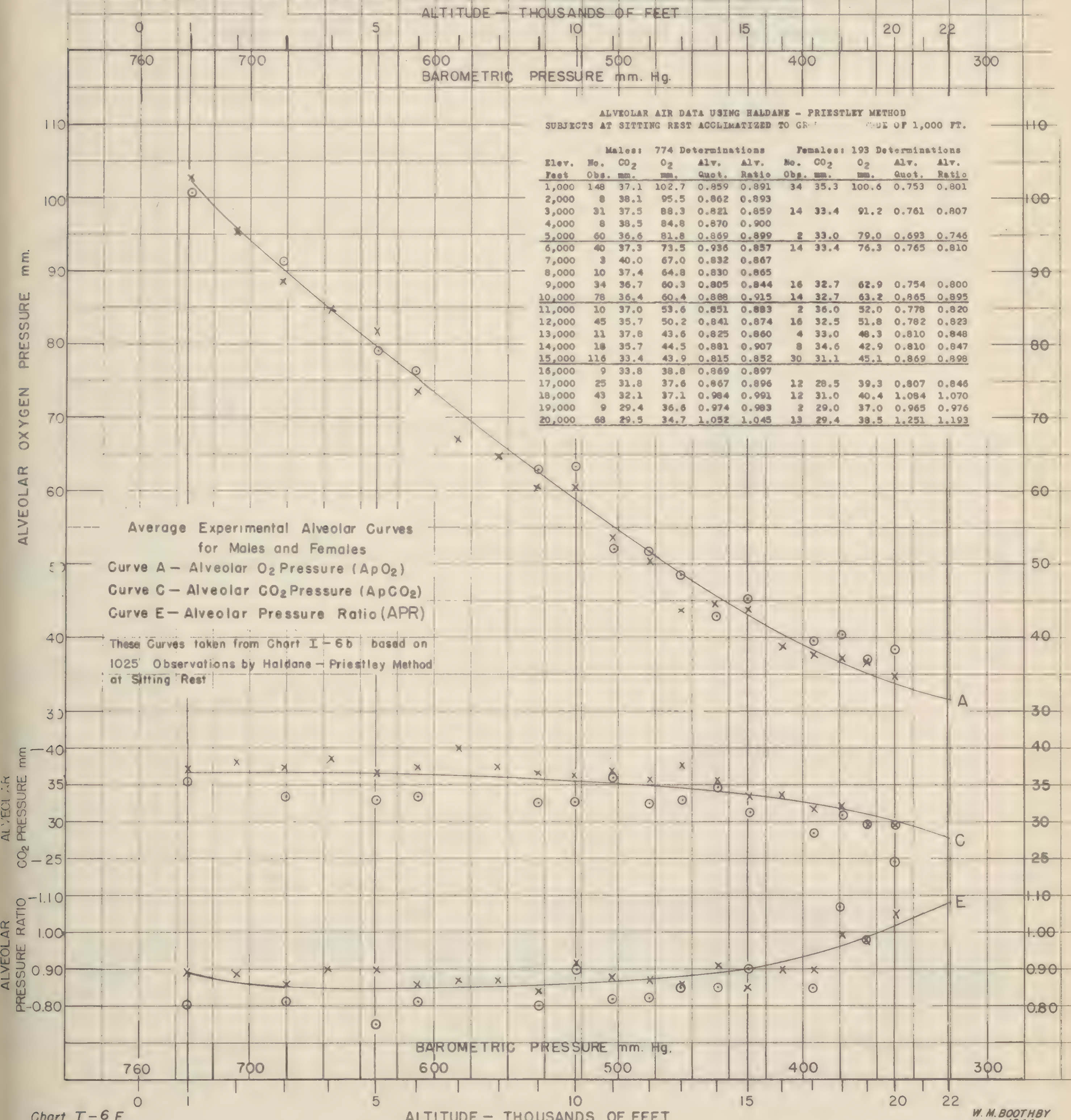
W. M. Boothby
Sept. 1944
Chart I-6b-1

Mayo Aero Medical Unit

COMPARISON OF MALES AND FEMALES

ALVEOLAR O_2, CO_2 AND ALVEOLAR RATIO PRESSURES AT VARIOUS ALTITUDES WHILE BREATHING AIR

AVERAGE OF MALES X   AVERAGE OF FEMALES O



ALVEOLAR AIR DATA USING HALDANE - PRIESTLEY METHOD
SUBJECTS AT SITTING REST ACCLIMATIZED TO GR[illegible]DE OF 1,000 FT.

	Males: 774 Determinations					Females: 193 Determinations				
Elev. Feet	No. Obs.	CO_2 mm.	O_2 mm.	Alv. Quot.	Alv. Ratio	No. Obs.	CO_2 mm.	O_2 mm.	Alv. Quot.	Alv. Ratio
1,000	148	37.1	102.7	0.859	0.891	34	35.3	100.6	0.753	0.801
2,000	8	38.1	95.5	0.862	0.893					
3,000	31	37.5	88.3	0.821	0.859	14	33.4	91.2	0.761	0.807
4,000	8	38.5	84.8	0.870	0.900					
5,000	60	36.6	81.8	0.869	0.899	2	33.0	79.0	0.693	0.746
6,000	40	37.3	73.5	0.936	0.857	14	33.4	76.3	0.765	0.810
7,000	3	40.0	67.0	0.832	0.867					
8,000	10	37.4	64.8	0.830	0.865					
9,000	34	36.7	60.3	0.805	0.844	16	32.7	62.9	0.754	0.800
10,000	78	36.4	60.4	0.888	0.915	14	32.7	63.2	0.865	0.895
11,000	10	37.0	53.6	0.851	0.883	2	36.0	52.0	0.778	0.820
12,000	45	35.7	50.2	0.841	0.874	16	32.5	51.8	0.782	0.823
13,000	11	37.8	43.6	0.825	0.860	4	33.0	48.3	0.810	0.848
14,000	18	35.7	44.5	0.881	0.907	8	34.6	42.9	0.810	0.847
15,000	116	33.4	43.9	0.815	0.852	30	31.1	45.1	0.869	0.898
16,000	9	33.8	38.8	0.869	0.897					
17,000	25	31.8	37.6	0.867	0.896	12	28.5	39.3	0.807	0.846
18,000	43	32.1	37.1	0.984	0.991	12	31.0	40.4	1.084	1.070
19,000	9	29.4	36.6	0.974	0.983	2	29.0	37.0	0.965	0.976
20,000	68	29.5	34.7	1.052	1.045	13	29.4	38.5	1.251	1.193

Chart I - 6 E   ALTITUDE — THOUSANDS OF FEET   W. M. BOOTHBY FEB. 1944

MAYO AERO MEDICAL UNIT

Alveolar O_2 and CO_2 Pressures and Alveolar Pressure Ratios as affected by Duration of Stay at 15,000 feet

Five subject were taken to 15,000 feet on "normal" oxygen, about 10 minutes at altitude mask was removed and alveolar airs obtained at intervals up to 90 minutes

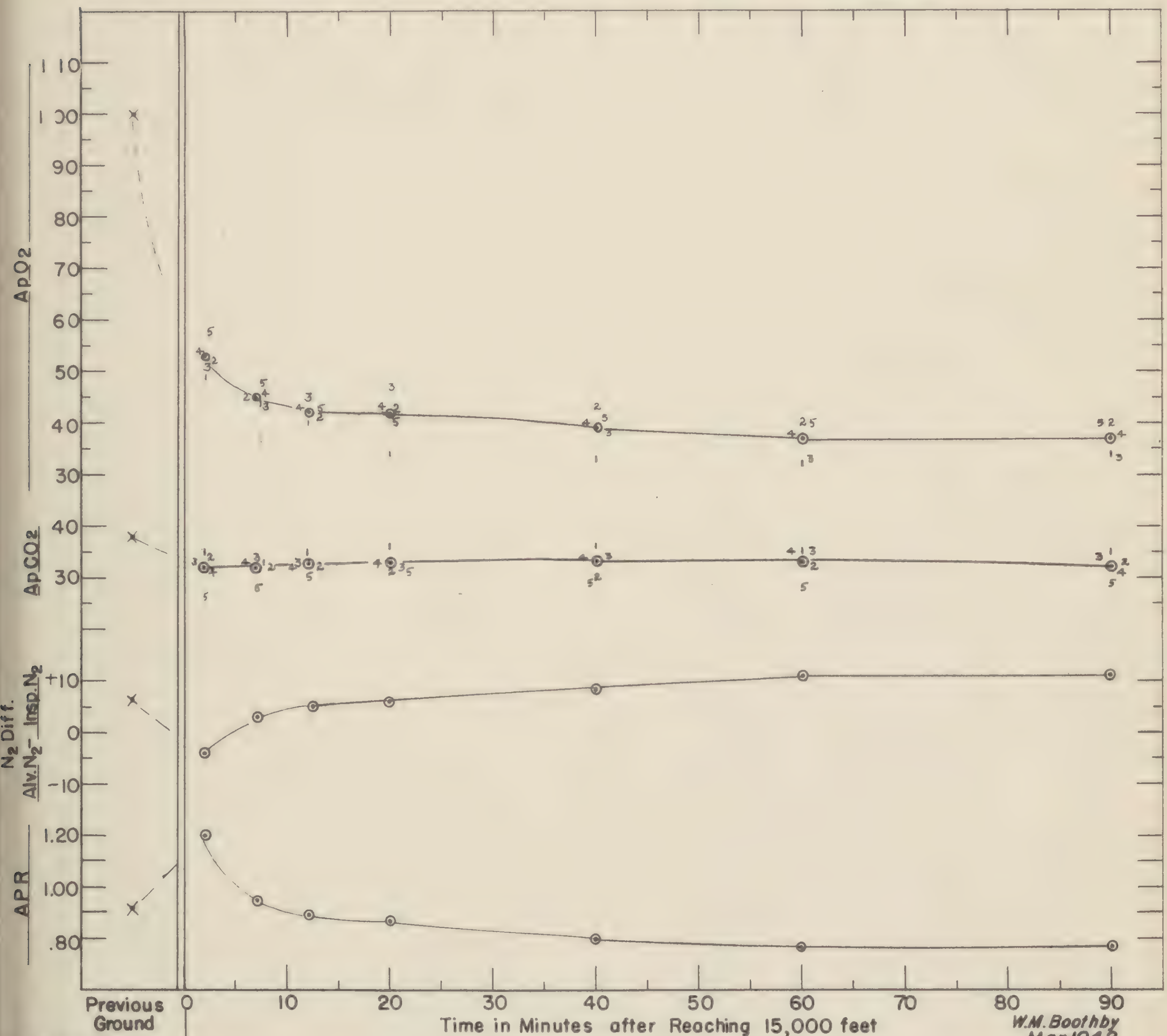
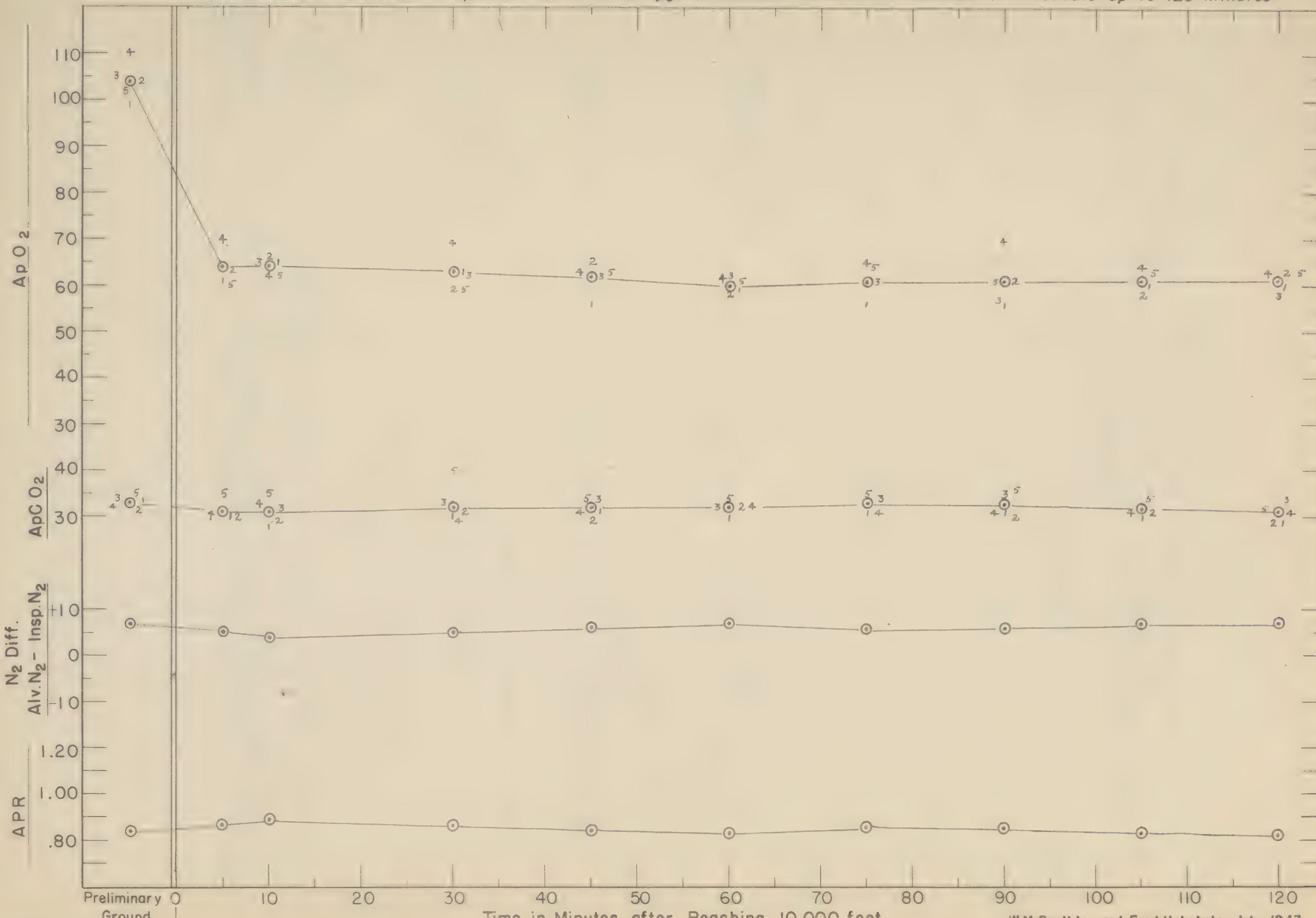


Chart I-10a

Mayo Aero Medical Unit

Alveolar O_2 and CO_2 Pressures and Alveolar Pressure Ratios as affected by Duration of Stay at 10,000 feet

Five subjects were taken to 10,000 feet without oxygen. Alveolar airs were obtained at intervals up to 120 minutes



W.M. Boothby and Fred Helmholz July 1943

Chart I — 10 b

Mayo Aero Medical Unit

Alveolar O_2 and CO_2 Pressures and Alveolar Pressure Ratios as affected by Duration of Stay at 15,000 feet

Six subjects went to 15,000 feet without Oxygen. Alveolar airs were obtained at intervals up to 90 minutes

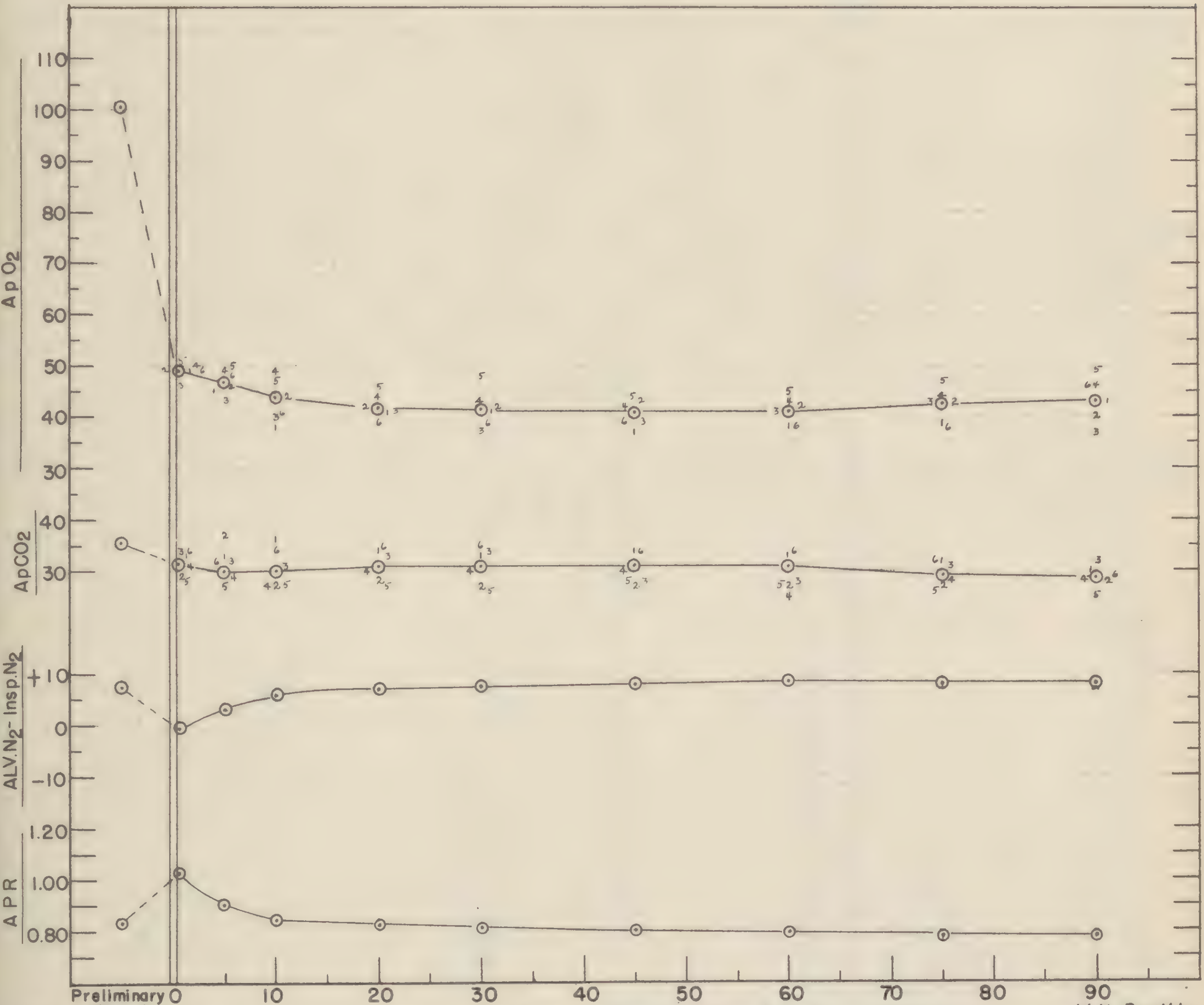
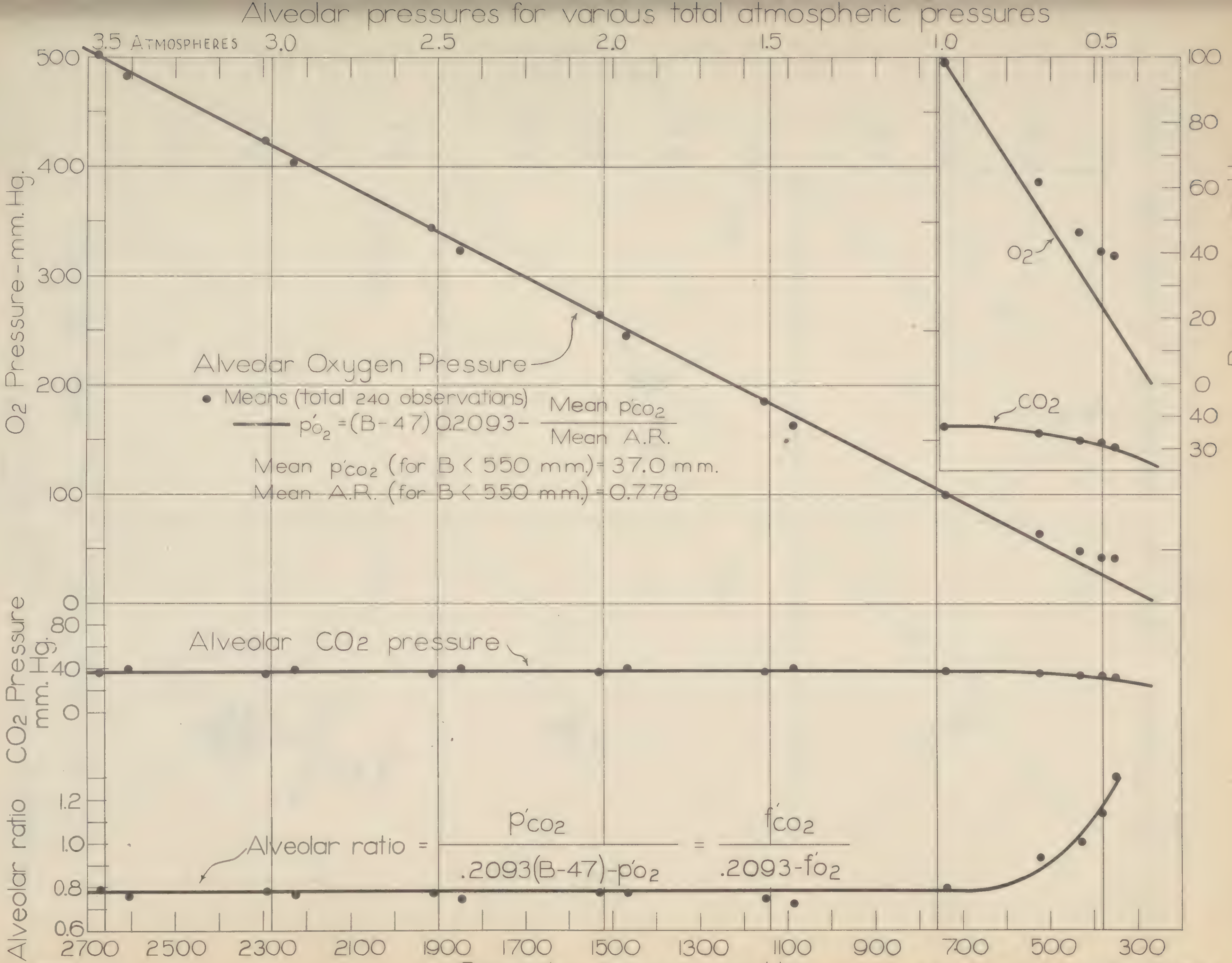


Chart I - 10 c *June 1944*

W. M. Boothby
J. B. Bateman

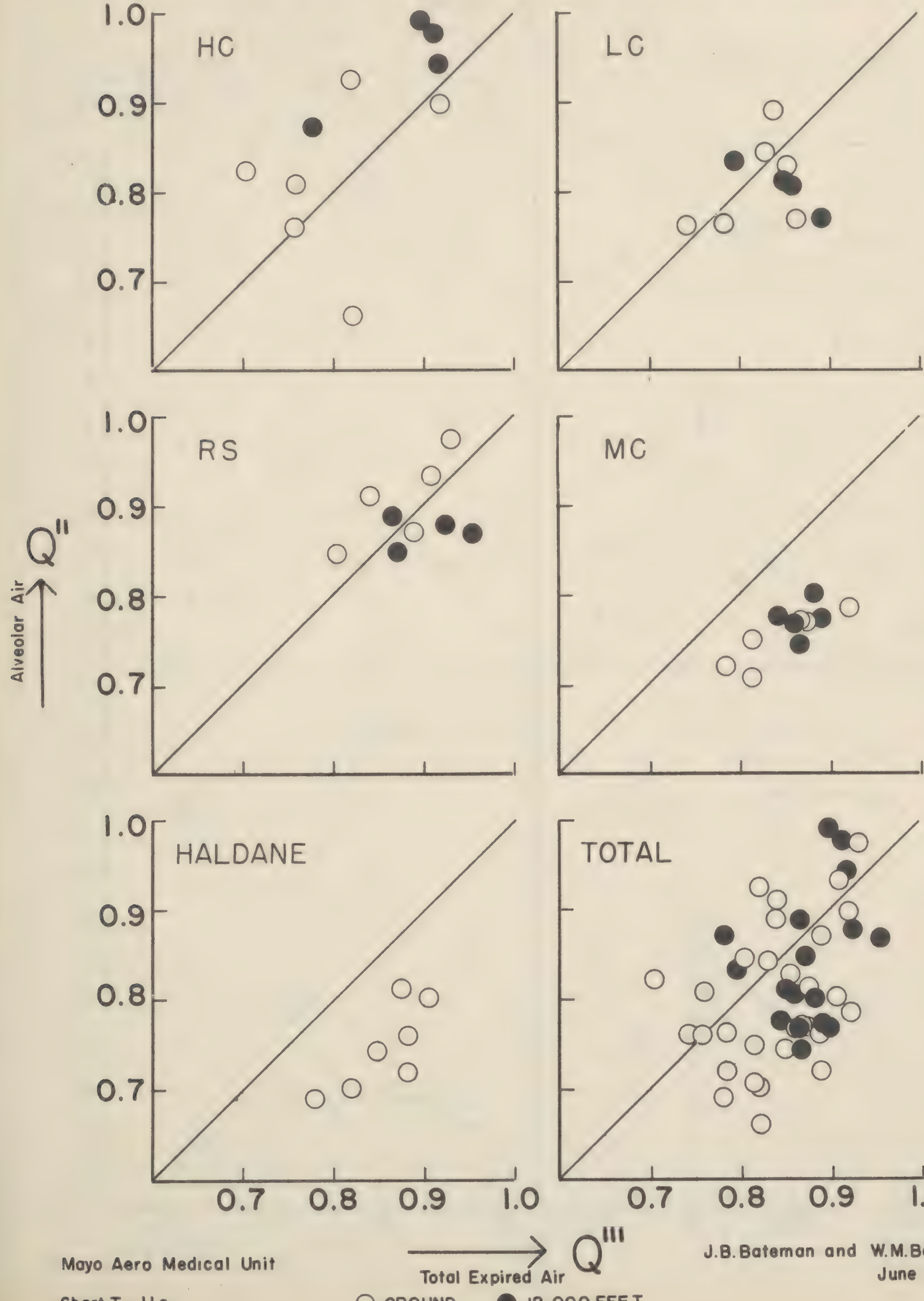


XII - 7a

DR. WALTER M. BOOTHBY May 1942

17

COMPARISON OF RESPIRATORY QUOTIENTS CALCULATED FROM ANALYSES OF ALVEOLAR AND TOTAL EXPIRED AIR



Mayo Aero Medical Unit

Chart I- 11a

J.B. Bateman and W.M. Boothby
June 1944

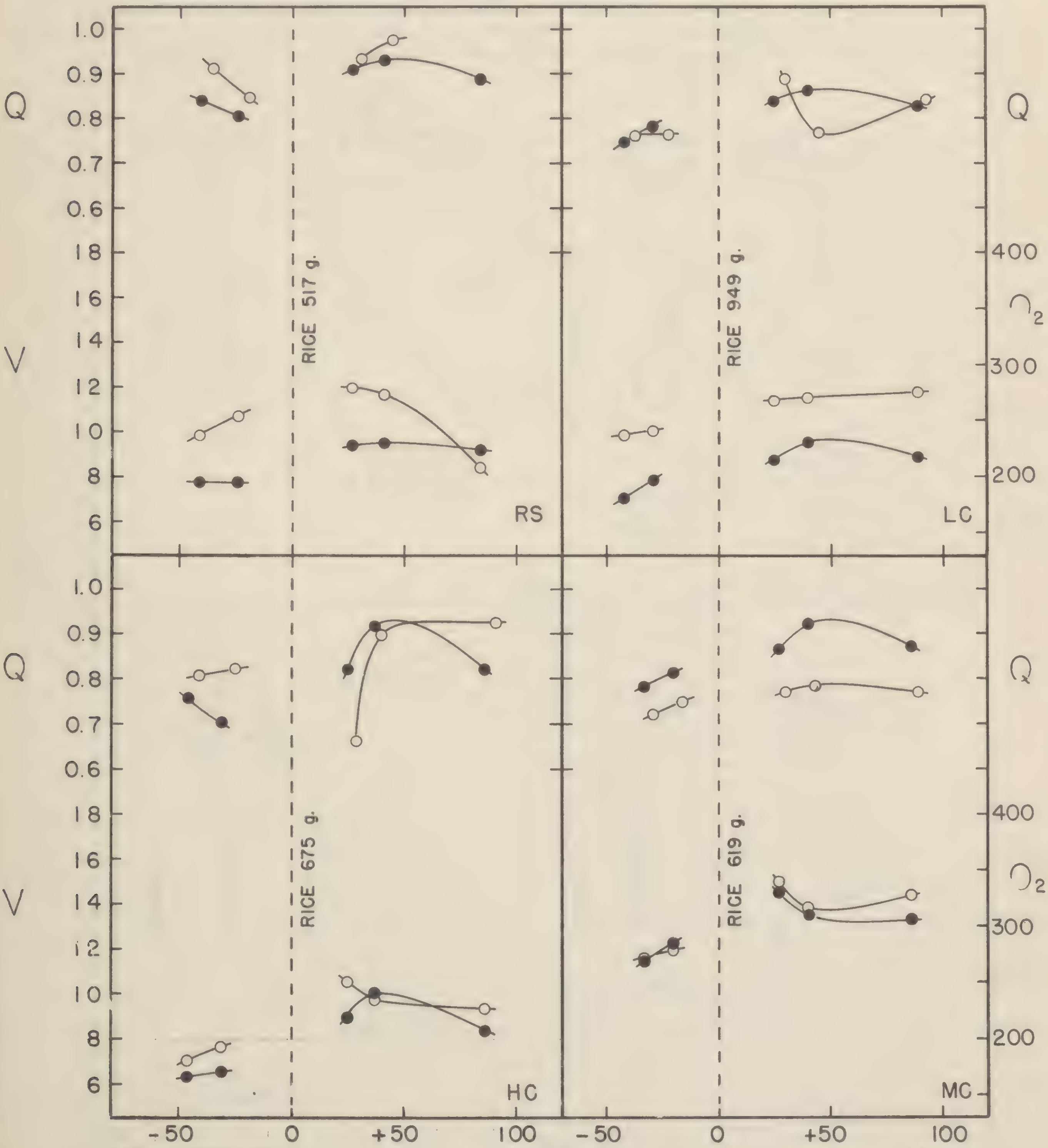
Fig. 1

18

TIME COURSE OF CHANGE OF TRUE RESPIRATORY QUOTIENT AND ALVEOLAR RESPIRATORY QUOTIENT AFTER A MEAL OF RICE

DATA OBTAINED AT GROUND LEVEL (1,000 FEET)

Upper section of each quadrant contains points for true respiratory quotient Q''' ● and for alveolar respiratory quotient Q'' O
Lower sections show ventilation rate in liters per minute (atmospheric pressure, 37° C, 47 mm. water vapor), ● and oxygen consumption in c.c. per minute at 760 mm., 0° C, dry.
Abscissa: time in minutes. Zero is time at which meal of rice was finished.



Mayo Aero Medical Unit
Chart I - IIb June 1944

J.B.Bateman
W.M.Boothby

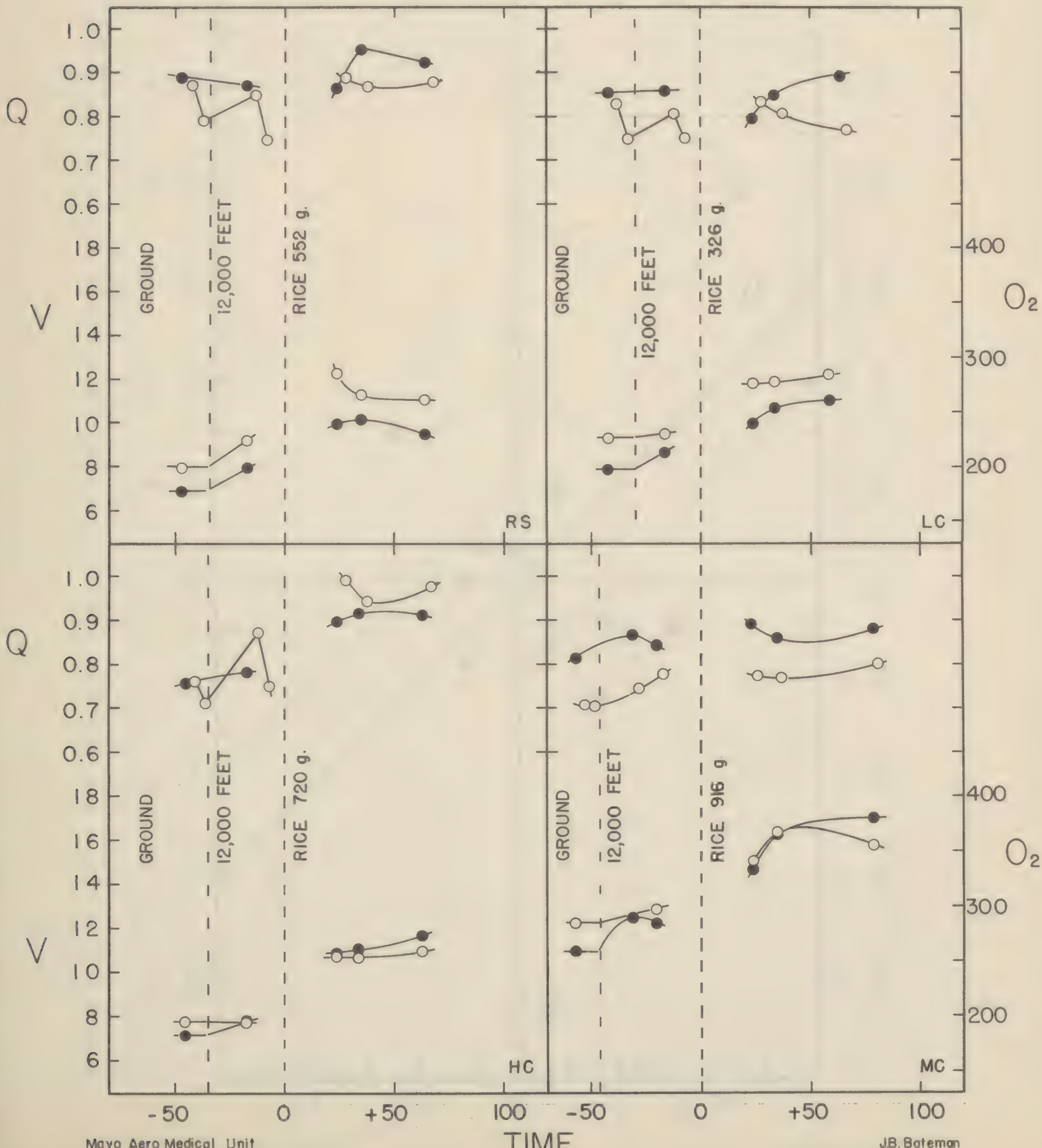
Fig. 2

TIME COURSE OF CHANGE OF TRUE RESPIRATORY QUOTIENT AND ALVEOLAR RESPIRATORY QUOTIENT AFTER A MEAL OF RICE

DATA OBTAINED AT 12,000 FEET SIMULATED ALTITUDE

Upper section of each quadrant contains points for true respiratory quotient, Q''', and for alveolar respiratory quotient, Q''.
Lower sections show ventilation rate in liters per minute (ambient pressure, 37°C, 47mm. water vapor), and oxygen consumption in cc. per minute at 760 mm., 0° C, dry
Abscissa: Time in minutes. Zero is time at which meal of rice was finished.
Dotted line on left of each qradrant shows point of ascent to 12,000 feet.

Q''' V	Q'' O_2
●	○



Mayo Aero Medical Unit
Chart I-11c June 1944

Fig. 3

J.B. Bateman
W.M.Boothby

COMPARISON OF OBSERVED CHANGES IN PARTIAL PRESSURES WITH THOSE CALCULATED FROM CHANGES IN RESPIRATORY QUOTIENT OCCURRING AFTER A MEAL OF RICE

Abscissa: Calculated change, $\Delta pC'' + \Delta pO''$. Ordinate: Measured change, $\Delta pC'' + \Delta pO''$

Units : Millimeters of mercury. O Ground level, 1,000 feet. ● 12,000 feet.

Points representing measured changes smaller than those calculated must all fall within sectors AOB and COD.

The pairs of lines parallel to AOD represent the average discrepancy between calculated and measured values.

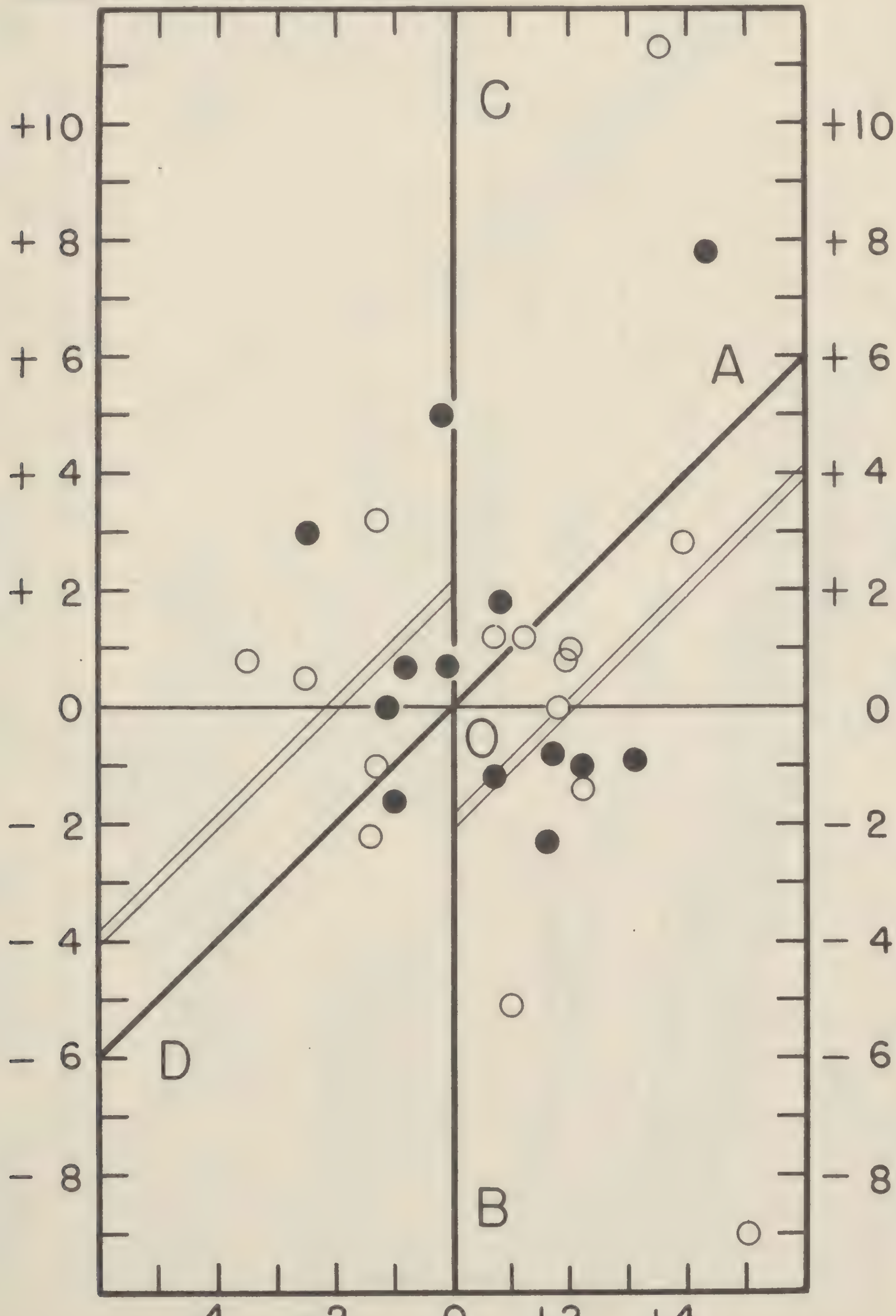


Fig. 5

Mayo Aero Medical Unit
Chart I–11e June 1944

J.B. Bateman
W.M. Boothby

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MAYO AERO MEDICAL UNIT

COMPARISON BETWEEN LOW ALTITUDES BREATHING AIR AND HIGH ALTITUDES BREATHING OXYGEN

based on over 1400 determinations of the alveolar air by the Haldane – Priestley method on subjects acclimatized to ground level of 1000 feet

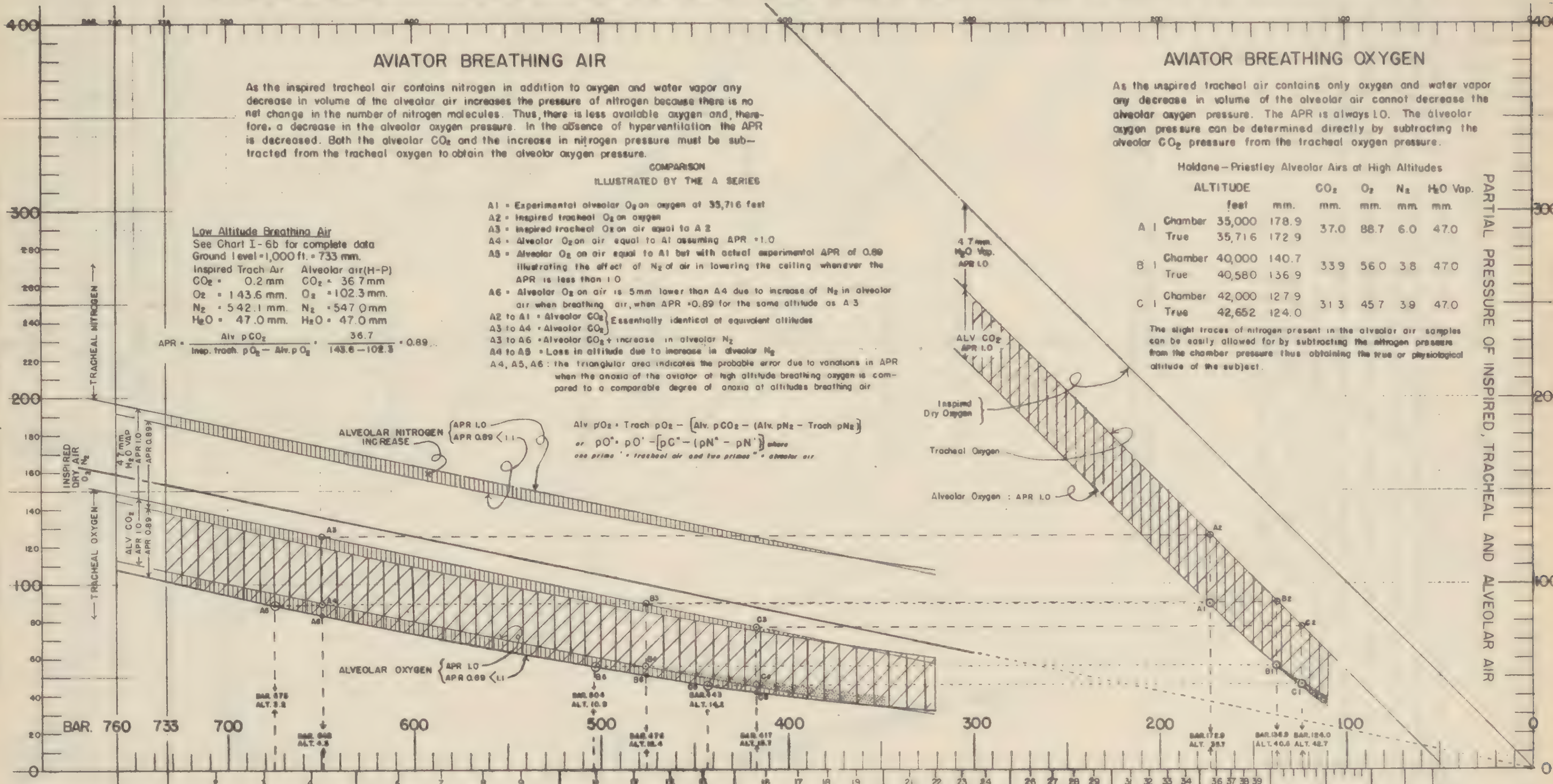


Chart I-6-d-b

W.M.Boothby Apr 1944

Mayo Aero Medical Unit

EFFECT OF ANOXIA ON ALVEOLAR AIR PRESSURES

AVIATOR BREATHING AIR AT VARIOUS ALTITUDES

The pressures of O_2, CO_2 and N_2 in the inspired tracheal air are characteristically altered during the respiratory cycle. In the "Steady State" these respiratory changes are based upon the character of food eaten which alters not only the partial pressures but also the total volume of the alveolar air from the inspired air. Altitude anoxia, dependent upon its intensity and duration, superimposes in the "Semi – Steady State" definite additional changes in the alveolar nitrogen, oxygen and carbon dioxide pressures and consequently upon the various ratios or quotients that can be calculated therefrom. The alveolar oxygen pressure can be calculated by the following formula:

$$pO'' = pO' - [pC'' + (pN'' - pN')]$$

One prime' = Tracheal air: Two primes" = Alveolar air

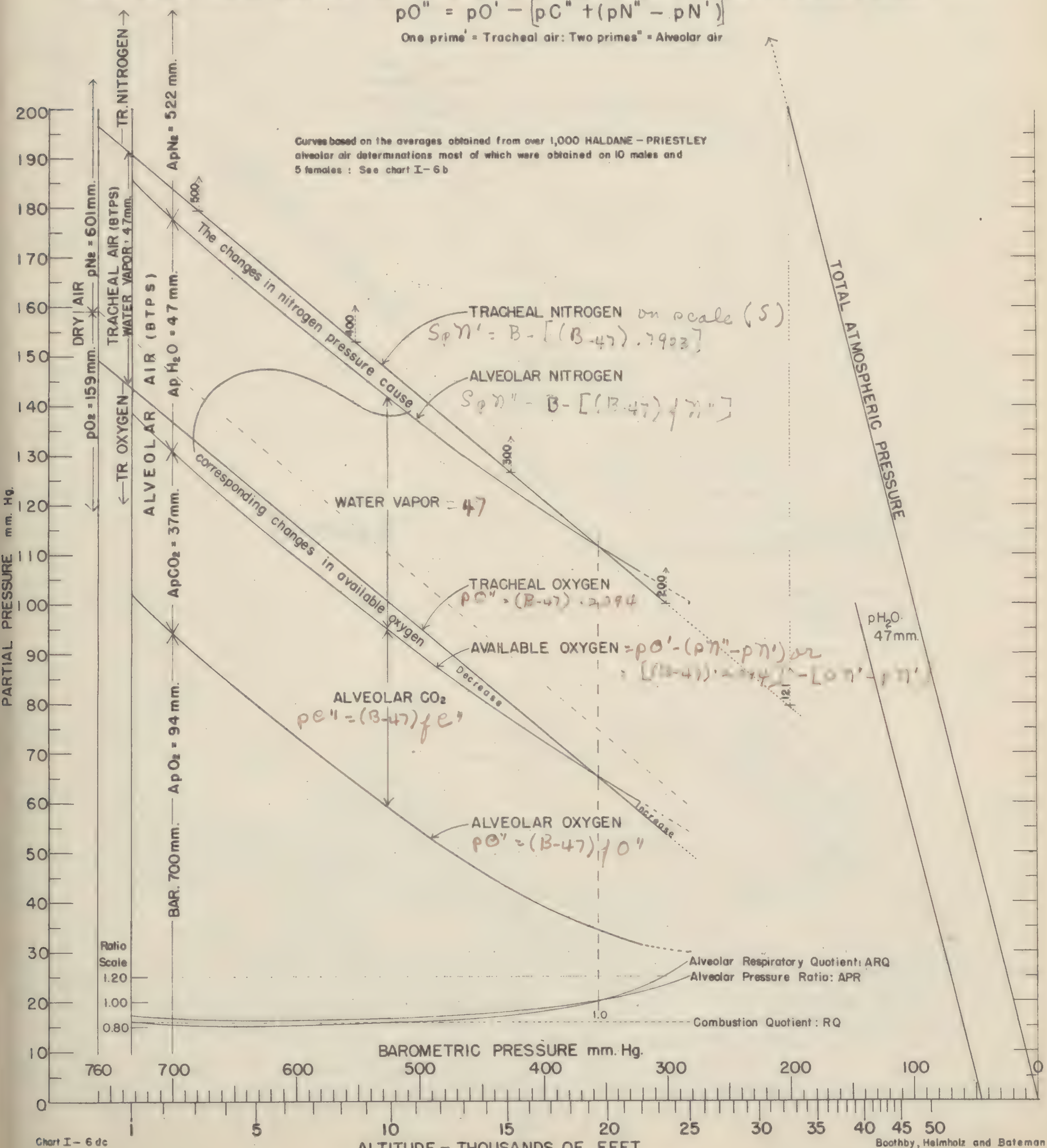


Chart I – 6 dc

Boothby, Helmholz and Bateman
June 1944

ATMOSPHERIC TRIANGLE

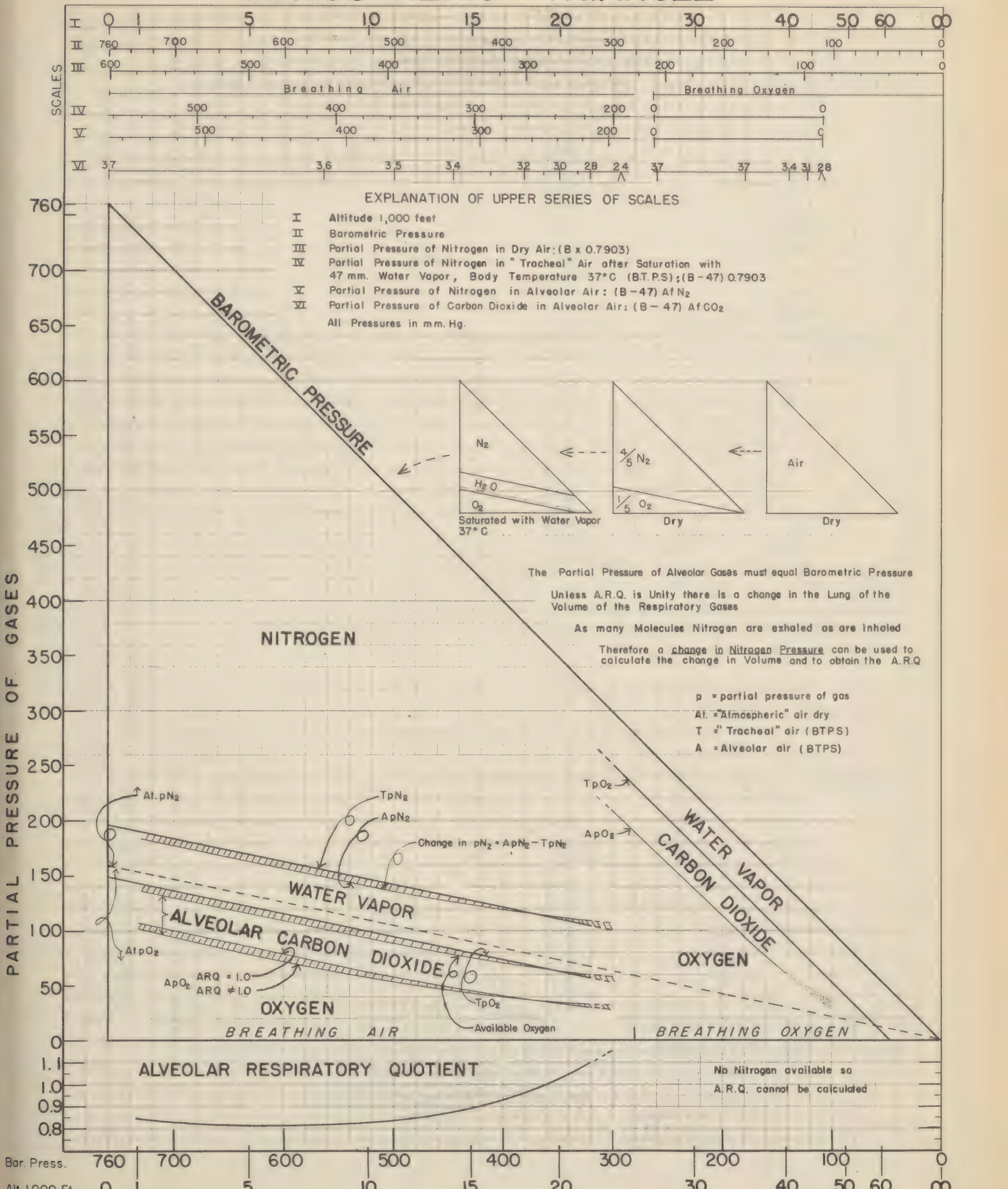


Chart I - 6d - e

J.B. Bateman and W.M. Boothby Aug. 1944

MAYO AERO MEDICAL UNIT

THE CHANGES IN APR. AND RQ.

(1.) After ascending to 18,000 ft. for 1 hour

(2.) After descending to ground (1,000 ft.) for 1 hour

$$APR = \frac{(AfCO_2 - IfCO_2)(B-47)}{(IfO_2 - AfO_2)(B-47)}$$

$$R.Q. = \frac{AfCO_2 - IfCO_2\frac{AfN_2}{IfN_2}}{IfO_2\frac{AfN_2}{IfN_2} - AfO_2}$$

● ALVEOLAR RATIO ⊙ ALVEOLAR RESPIRATORY QUOTIENT

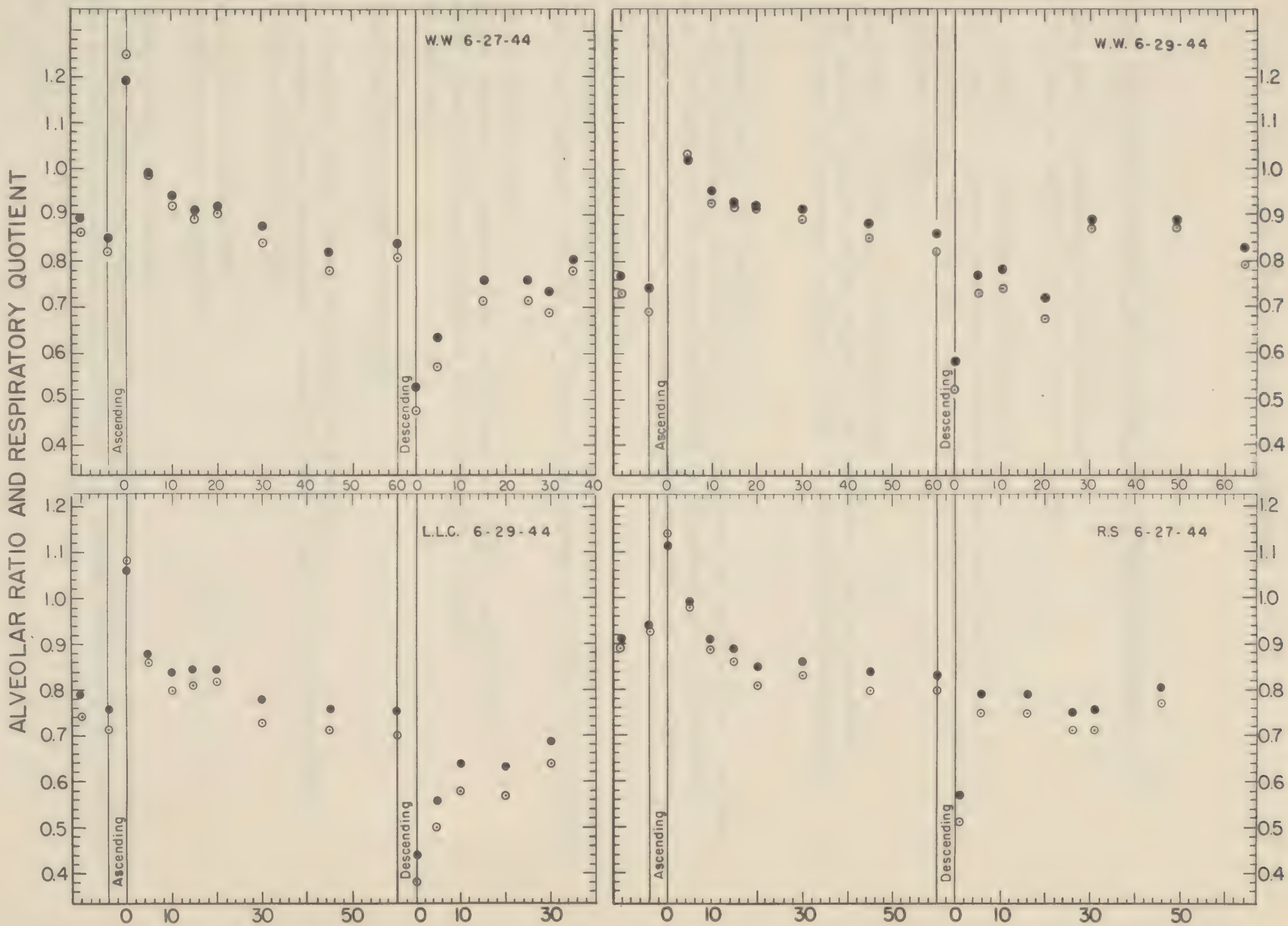


CHART I-6b-2

Fred Helmholz and W.M. Boothby Dec., 1945

MAYO AERO MEDICAL UNIT

DATA FROM HIGH ALTITUDE LABORATORY

Group II

EFFECT OF ALTITUDE ON OXYGEN PRESSURE IN THE LUNG AND OXYGEN REQUIREMENT

(1) XII-4 May 1942, J.Berkson and W.M.Boothby
Change of alveolar oxygen pressure with altitude.

(2) XII-5 May 1942, J. Berkson and W.M.Boothby
Change of alveolar oxygen pressure with altitude and its effect on (a) dry atmospheric inspired air and (b) air saturated with mositure at 97°C (tracheal air).

(3) XII-6 May 1942, J.Berkson and W.M.Boothby
Liters of oxygen necessary to maintain at altitude oxygen pressure normal (149 mm) in tracheal air per liter of ventilation measured at BTPS.

(4) XII-13 August 1943, W.M.Boothby
Oxygen and air added to inspired mixture required to maintain at various altitudes the pressure of oxygen existing in tracheal air at the sea level equivalent of 149 mm. expressed volumetrically and by weight.

(5) XII-11 June 1943 H.F.Helmholz Jr.
Effect of temperature change, water vapor and pressure change in reducing a constant ventilation rate of 10 liters per minute P.T.P.S. L S.T.P.D.

(6) V-1a 1940, W.M.Boothby
Comparative rates of oxygen flow expressed at STPD needed by
I Constant flow (a) Manual control (b) Automatic aneroid
II Demand Method

(7) V-2a Same as (6) but expressed BTPS

(8) XII-14 December 1944, Swann modified by Boothby
Rates of oxygen flow per minute compared with oximeter data obtained by Capt. Swann at Wright Field.

(9) 2c March 1942, W.M.Boothby
Oxygen requirement for aviators

(10) 2ga August 1943, W.M.Boothby
Table showing oxygen and air added to 10 L (BTPS) inspired air required to maintain at various altitudes the pressure of oxygen existing in tracheal air of sea level equivalent of 149.3 mm. Data for chart XII-13 No. 4 in this series.

MAYO AERO MEDICAL UNIT

DATA FROM HIGH ALTITUDE LABORATORY

EFFECT OF ALTITUDE ON OXYGEN PRESSURE IN THE LUNG AND OXYGEN REQUIREMENT.

(11) 2G(a) August 1943, W.M.Boothby
(a) Pressure and percent oxygen needed in Inspired Air Dry to maintain tracheal air at 149.3 mm. = Sea Level Equivalent
(b) Amount of oxygen used from cylinders, subject breathing at rate 10, 20, and 30 L/min.

(12) 2G)b) August 1943, W.M.Boothby
Same as 10 but for 122.5 mm. = 5,000 ft. equivalent

(13) 2G(c) August 1943, W.M.Boothby
Same as (10) for 117.7 mm. = 6,000 ft. equivalent

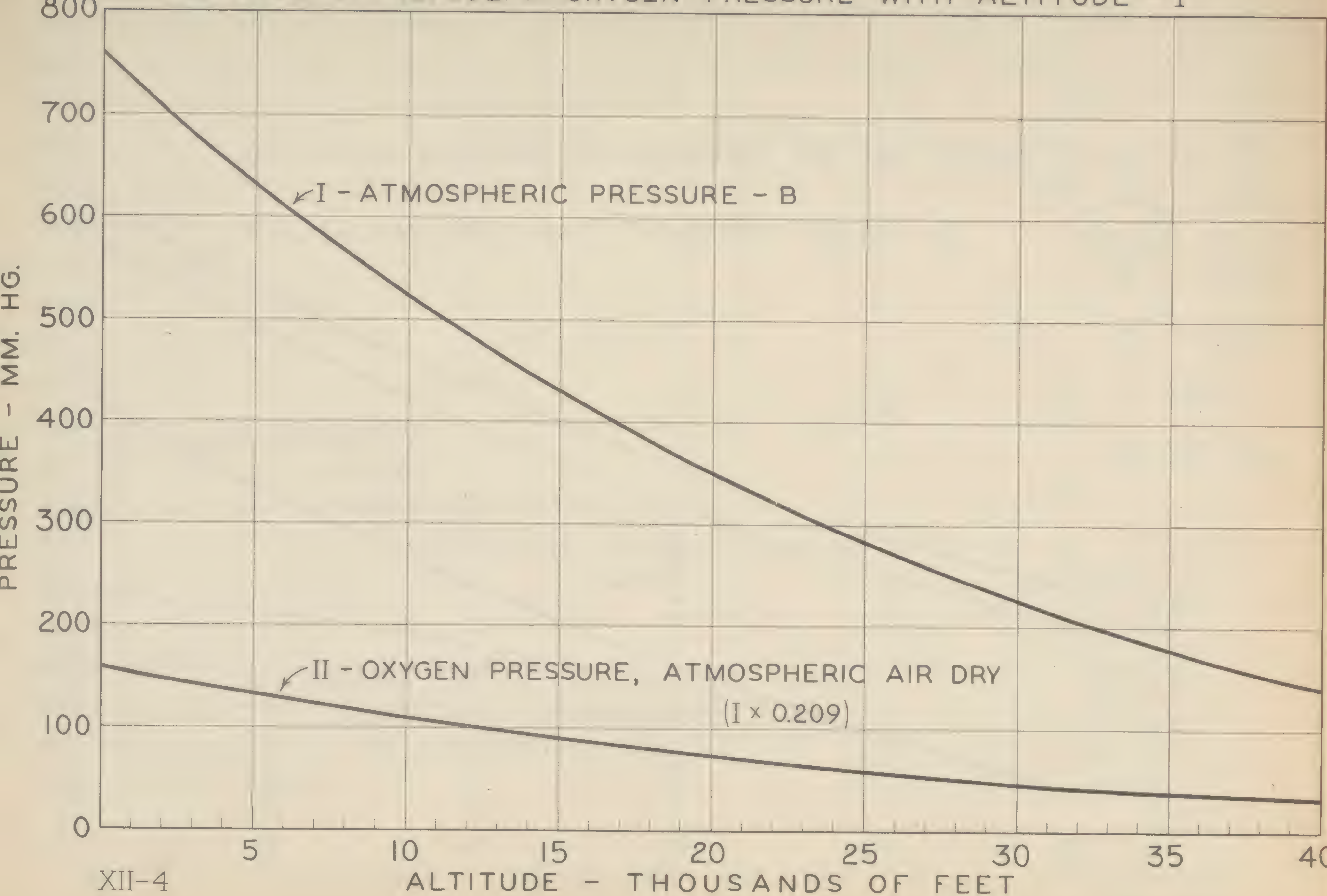
(14) 2G(d) August 1943, W.M.Boothby
Method of calculation (10), (11), (12), and (14)

(15) 2G(f) August 1943, W.M.Boothby
Same as (10) for 143.6 mm. = 1,000 ft. equivalent (Rochester)

(16) XVIII-1a July 1943, W.M.Boothby
Amount of oxygen saved by using Diluter on Demand Valve.

(17) XVIII-1b July 1943, W.M.Boothby
Further saving of oxygen by using both "Diluter" and "Economizer Bag" with Demand Valve.

CHANGE OF ALVEOLAR OXYGEN PRESSURE WITH ALTITUDE - 1

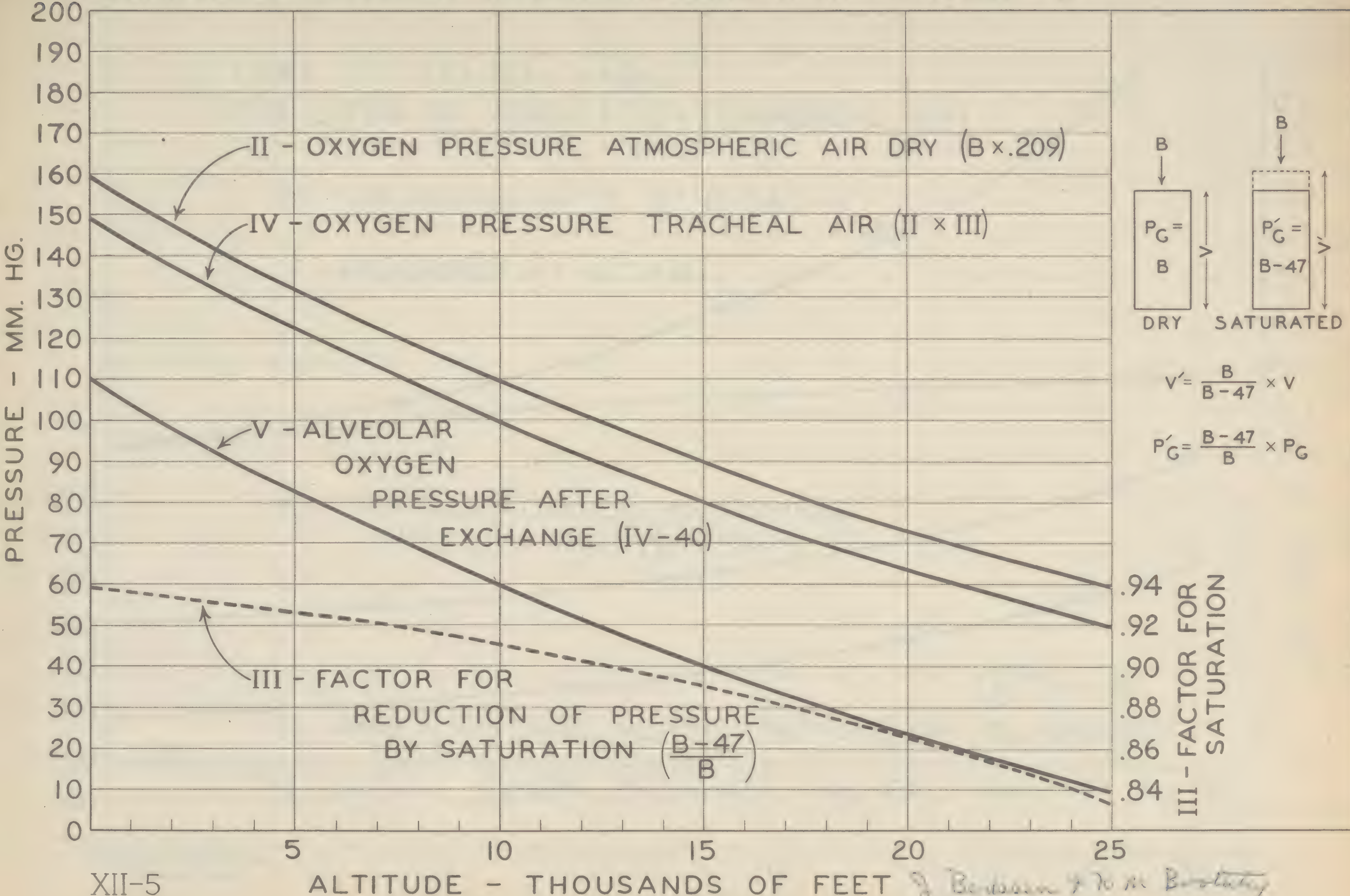


XII-4

(1)

J. Berkson + Wm. Boothby
May 1942

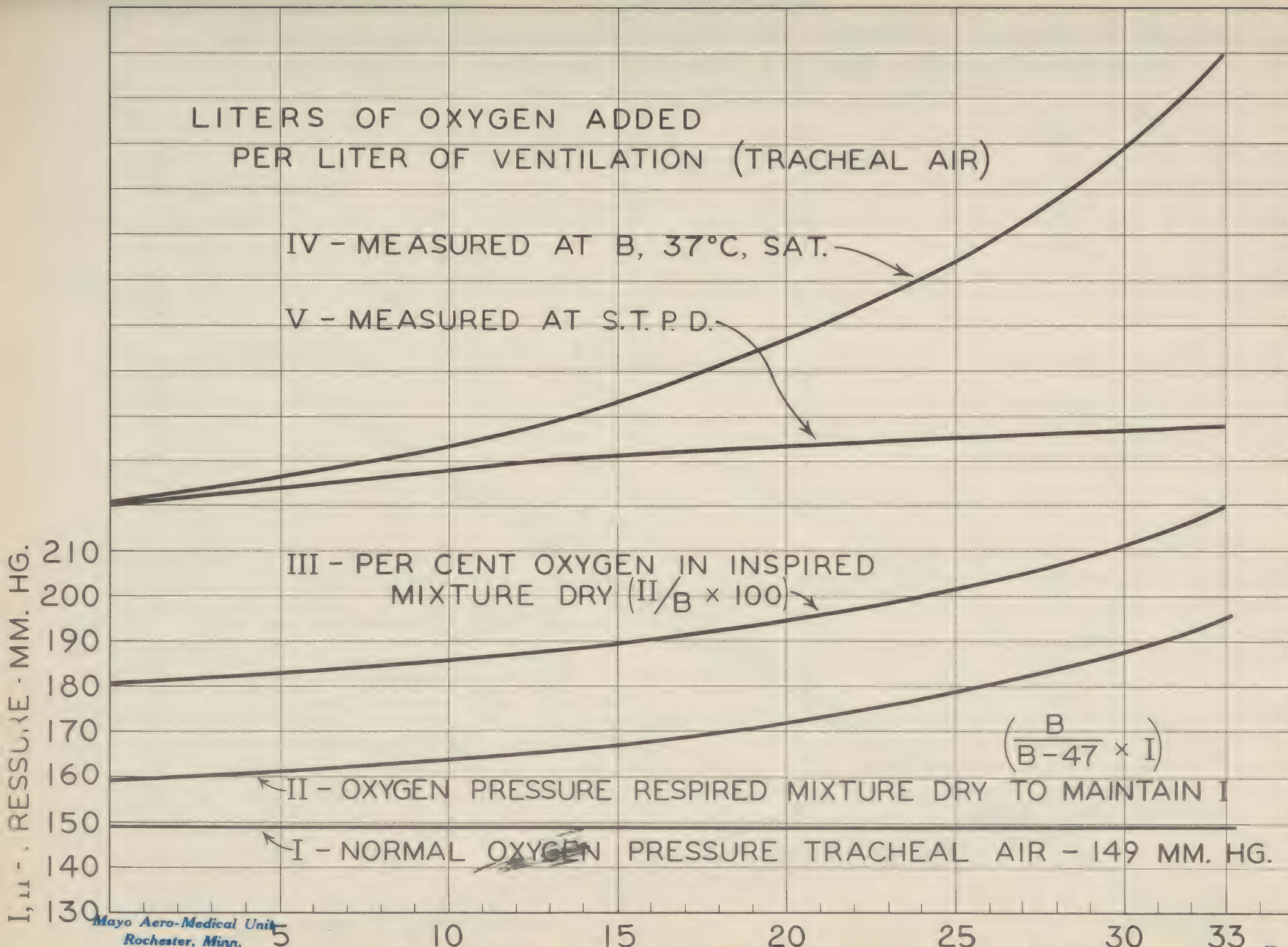
CHANGE OF ALVEOLAR OXYGEN PRESSURE WITH ALTITUDE - 2



XII-5

May 1942

(2)



Mayo Aero-Medical Unit
Rochester, Minn.

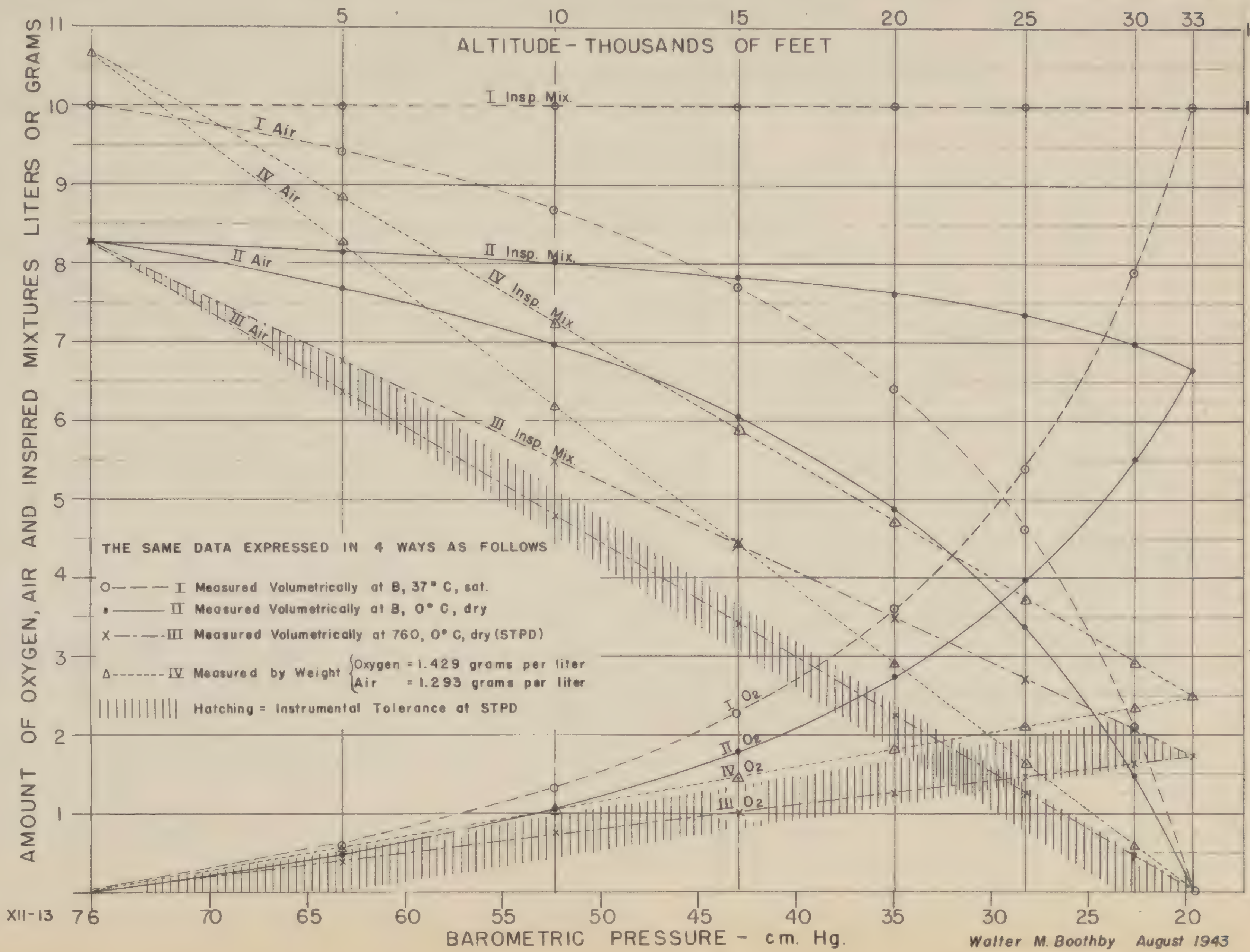
XII-6

G. Barbour & W.M. Boothby
May 1942

(3)

Mayo Aero Medical Unit

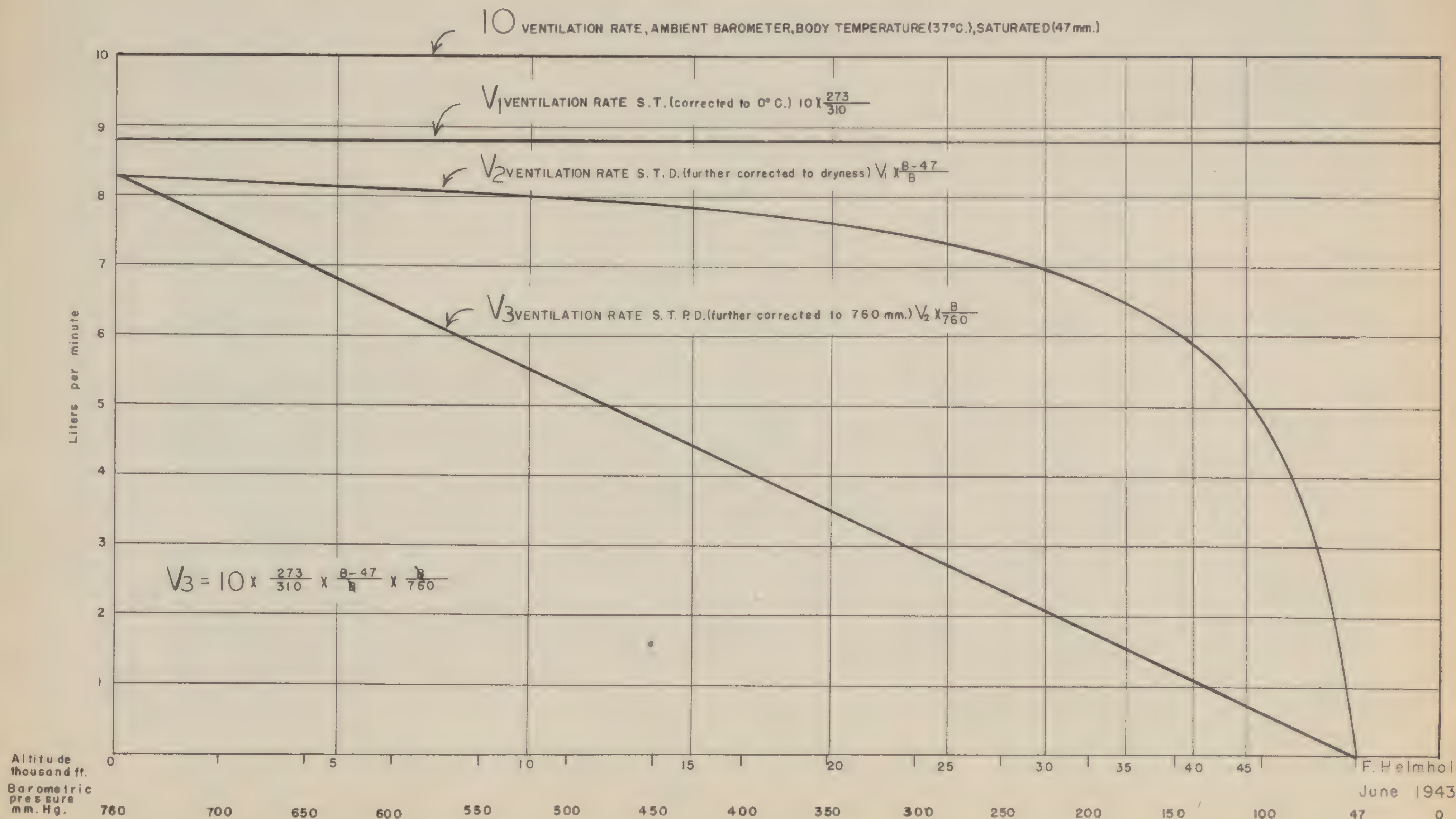
OXYGEN and AIR ADDED to INSPIRED MIXTURE REQUIRED to MAINTAIN at VARIOUS ALTITUDES the PRESSURE of OXYGEN EXISTING in TRACHEAL AIR at the SEA LEVEL EQUIVALENT of 149.3



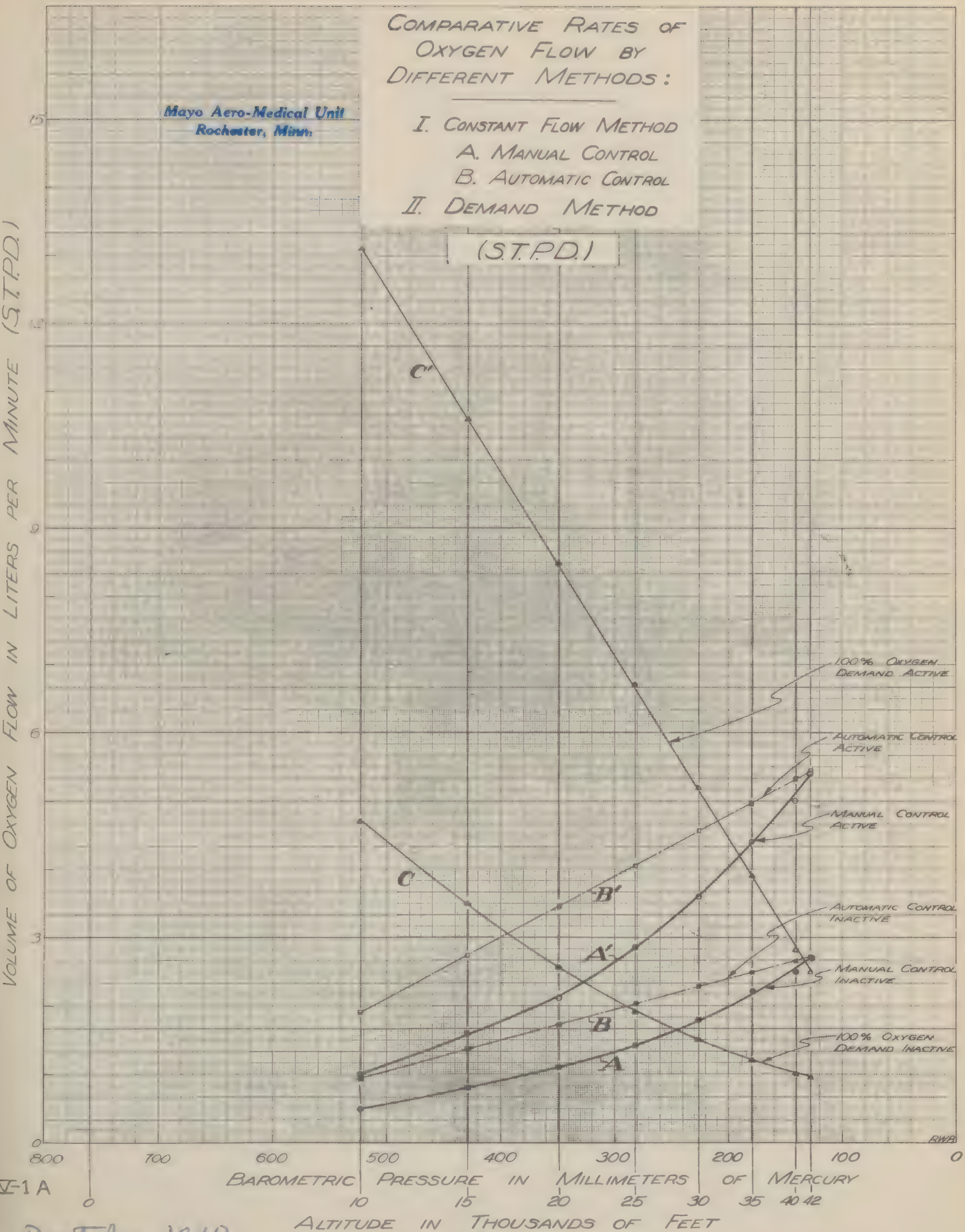
XII-13

Walter M. Boothby August 1943

EFFECT OF TEMPERATURE CHANGE, WATER VAPOR, AND PRESSURE CHANGE IN REDUCING A CONSTANT VENTILATION RATE, 10 L. PER MIN., TO S. T. P. D.



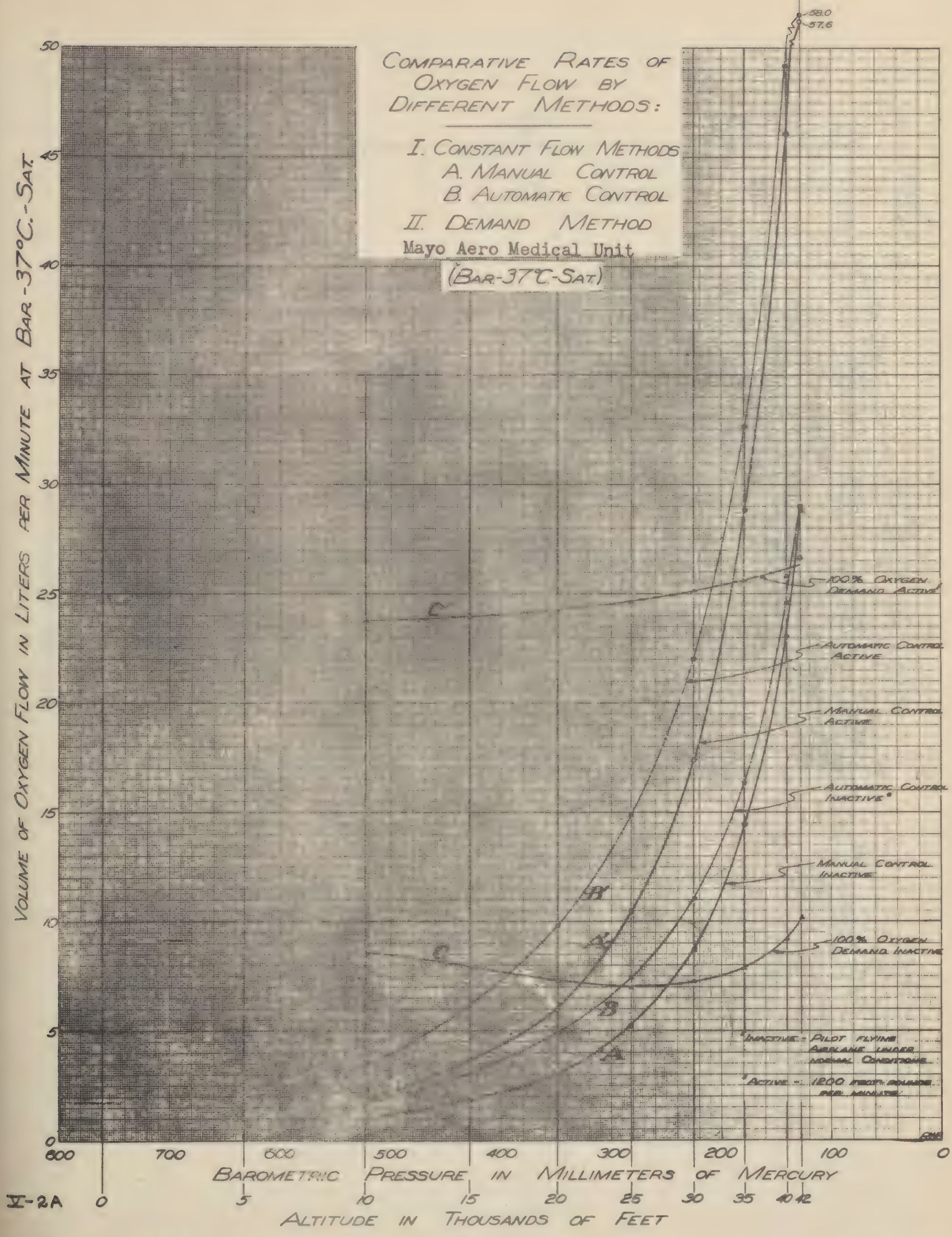
c-6 y+2



V-1 A

m Boothby 1940

6



V-2A

Boothby 1940

W-8008, AF

MAYO AERO MEDICALAL UNIT

Walter M. Boothby

COMPARISON OF THE OXIMETER DATA OBTAINED BY

Capt. H.G. Swann

TSEAL3-696-42 H

Dec. 30, 1944

With other pertinent observations

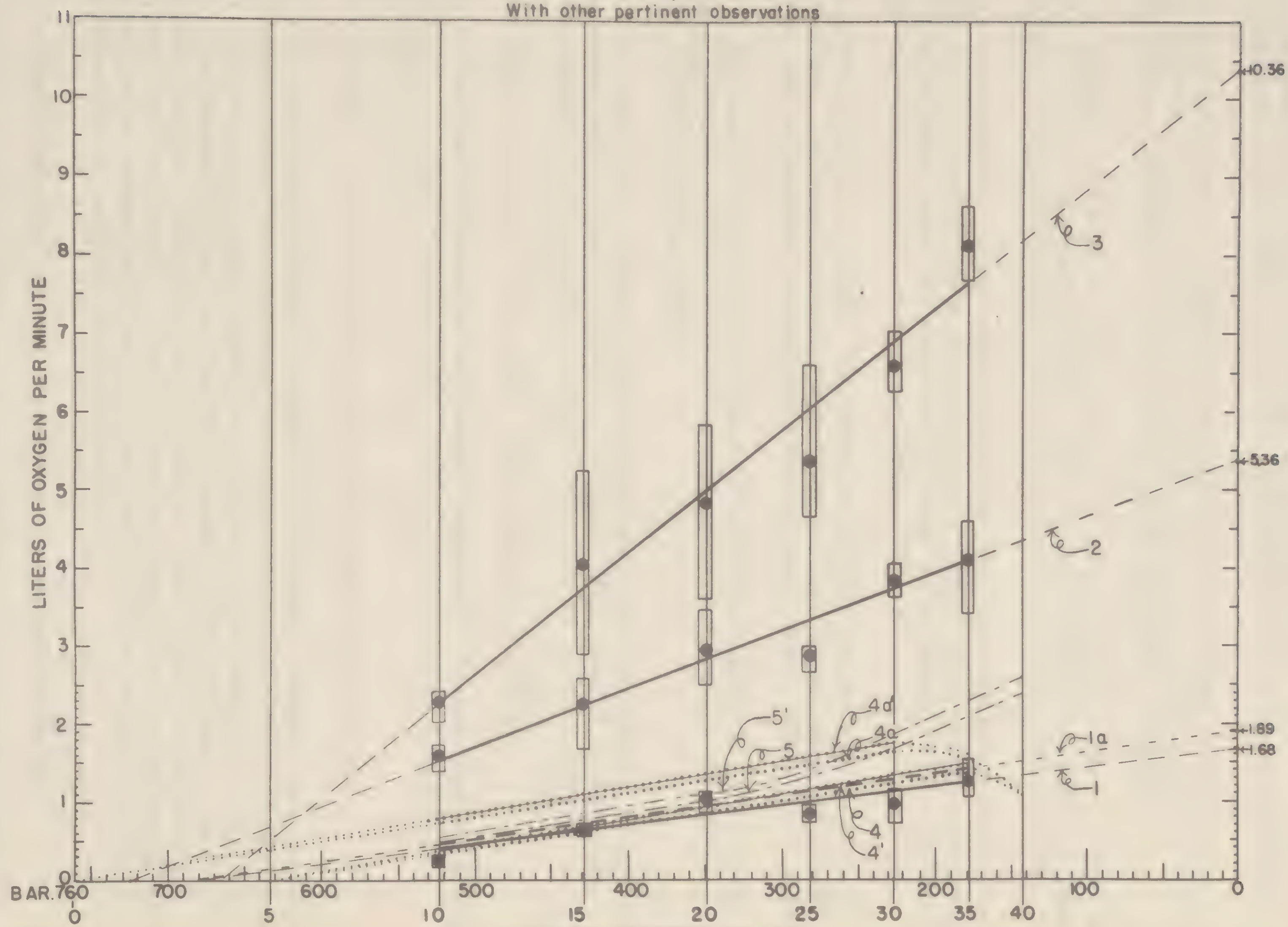


Chart XII-14

Jan. 1945

LEGEND CHART XII-14

STPD = Standard temperature and pressure, dry: 760 mm., 0°C, dry
NTPD = Normal temperature and pressure, dry: 760 mm. 70°F, dry
BTPS = Body temperature and ambient pressure, saturated with moisture: Bar. 37°C, Sat.

Swann's data for curves 1, 2 and 3 are indicated by a large solid circle for the average of 3 determinations and the upper and lower of these determinations are indicated by the oblong block expressed at NTPD.

Curve 1 - Oxygen flow required for subject at sitting rest. Curve fitted to data by method of least squares. The average ventilation rate of same subjects under similar conditions was found to be 8.9 L/min., BTPS.

Curve 1a - Similar to curve 1 but calculated for the standard resting ventilation rate at sitting rest of 10.0 L/min., BTPS. (This allows easy comparison with other data the majority of which is calculated for a standard resting ventilation rate of 10.0 L/min., BTPS.)

Curve 2 - Subjects on a bicycle ergometer doing work equivalent to 2400 ft. lbs./min. The same subjects when doing similar experiments at ground level had an average ventilation rate of 26.4 L/min., BTPS.

Curve 3 - Subjects doing work equivalent to 4200 ft. lbs./min. In similar experiments on same subjects at ground level the average ventilation rate was 40.7 L/min., BTPS.

Curve 4 - "5,000 foot" standard oxygen requirement for the demand regulator. The curve represents the liters of oxygen, STPD, needed to maintain tracheal pO_2 = 123 mm. with subject breathing 10 L/min., BTPS.

Curve 4' - Same as curve 4 but oxygen flow expressed at NTPD.

Curve 4a - "Sea level" standard for demand regulator. Liters oxygen, STPD, needed to maintain tracheal pO_2 = 149 mm. with subject breathing 10 L/min., BTPS.

Curve 4a' - Same as curve 5 except oxygen flow expressed at NTPD.

Curve 5 - Liters oxygen, STPD, recommended by Boothby, Lovelace and Benson for use with constant flow BLB mask (750 cc. reservoir). Their recommendation corresponds approximately to a "4,000 foot" standard to 20,000 feet and increasing to "sea level" standard at 30,000 feet. Above this altitude oxygen flows increased to 2.4 L STPD to give an excess at 40,000 feet for safety. Note in attached chart that these oxygen flows maintained an essentially normal alveolar pO_2 up to 40,000 feet on a large number of subjects at sitting rest.

Curve 5' - Same as curve 5 except oxygen flow expressed at NTPD.

Comment on paper by Captain H.G.Swann: "Oxygen Requirements with Constant Flow Equipment."

OXYGEN REQUIREMENT FOR AVIATORS

Oxygen requirement for aviators at various altitudes per liter of ventilation: The ventilation is always measured at ambient barometer, 37° C. and saturated. The oxygen is measured at (1) ambient barometer, 37° C. saturated and at (2) S.T.P.D.

Requirement I: The amount of oxygen needed per liter of ventilation to keep the tracheal air and therefore the alveolar air normal as at sea level up to 33,000 feet where pure oxygen must be used. To maintain the alveolar air normal, the oxygen pressure in the tracheal air must be kept at 149 mm.

Requirement II: The amount of oxygen needed per liter of ventilation to maintain the tracheal and therefore the alveolar air as though the aviator were at an elevation of 6000 up to 37,000 feet (36,800 ft.) where pure oxygen must be used. To maintain the alveolar air equivalent to 6000 feet, the oxygen pressure in the tracheal air must be kept at 117 mm.

Altitude in thousands of feet	Barometer	A. Requirement I. Sea level tracheal O_2 = 149 mm. Amount O_2 needed per liter of ventilation at Bar. 37° C. Sat. Oxygen measured at		B. Requirement II. 6000 ft. tracheal O_2 = 117 mm. Amount O_2 needed per liter ventilation at Bar. 37° C. Sat. Oxygen measured at		C. B.L.B. Recommendation per liter ventilation at Bar. 37° C. Sat. Oxygen measured at	
		Bar. 37° C. Sat.	S.T.P.D.	Bar. 37° C. Sat.	S.T.P.D.	Bar. 37° C. Sat.	S.T.P.D.
5	632	0.06	0.04	—	—	—	—
10	523	0.13	0.07	0.05	0.03	0.09	0.05
15	429	0.23	0.10	0.12	0.05	0.18	0.08
20	349	0.36*	0.13	0.23	0.08	0.28	0.10
25	282	0.54	0.15	0.37	0.10	0.51	0.14
30	226	0.79	0.16	0.56	0.12	0.87	0.18
33	196	1.00	0.17	0.73	0.12		
35	179	1.00	0.15	0.80	0.12	1.45**	0.22
37	164	1.00	0.13	1.00	0.13		
40	141	1.00	0.11	1.00	0.11	2.69**	0.25

* For example, for each liter inspired the mixture is composed of 0.36 liters oxygen taken from the tank and 0.64 liters taken from the atmosphere, both measured at Bar. 37° C. Sat. The value 0.36 liters is reduced to 0.13 liters when measured at S.T.P.D. which is the convenient expression for the supply officer to calculate the amount available in his tanks as the oxygen in the tanks is dry.

** Note the safety factor as the result of the excess flow at high altitudes.

Table 2 c
March 1942

MAYO AERO MEDICAL UNIT

OXYGEN AND AIR ADDED TO INSPIRED MIXTURE REQUIRED TO MAINTAIN AT VARIOUS ALTITUDES
THE PRESSURE OF OXYGEN EXISTING IN TRACHEAL AIR OF THE SEA LEVEL EQUIVALENT OF 149.3 MM.
WITH A SUGGESTED LIMIT OF TOLERANCE FOR THE MANUFACTURER

		I			II			III			IV		
		Measured at B. 37° C. sat.			Measured at B. 0° C. Dry			Measured at 760, 0° C. Dry			Weighed at 760, 0° C. Dry		
Elevation	Bar. Press.	O_2	Air	Vt.	O_2	Air	Vt.	O_2	Air	Vt	O_2	Air	Vt.
Feet	mm.	Liters	Liters	Liters	Liters	Liters	Liters	Liters	Liters	Liters	Grams	Grams	Grams
0	760		10.0	10.0	0	8.26	8.26	0	8.262	8.26	0	10.683	10.683
5,000	632	0.58	9.42	10.0	0.47	7.68	8.15	0.393	6.385	6.78	0.562	8.256	8.818
10,000	523	1.32	8.68	10.0	1.06	6.96	8.01	0.728	4.787	5.51	1.040	6.190	7.230
15,000	429	2.29	7.71	10.0	1.80	6.05	7.84	1.014	3.412	4.43	1.449	4.412	5.861
20,000	349	3.60	6.40	10.0	2.74	4.88	7.62	1.260	2.240	3.50	1.801	2.896	4.697
25,000	282	5.39	4.61	10.0	3.96	3.38	7.34	1.468	1.255	2.72	2.098	1.623	3.721
30,000	226	7.90	2.10	10.0	5.51	1.46	6.97	1.633	0.436	2.07	2.341	0.564	2.905
33,000	196	10.02	0	10.0	6.66	0	6.69	1.730	0	1.73	2.472	0	2.472
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
		O_2 from Table 2 G a	Col. 4 = 10 L. - Col.3	Aviator quiet Vt. = 10 L.	Cols. 6, 7 and 8 are Cols. 3, 4 and 5 multiplied by factor $\frac{B-47}{B} \times \frac{273}{273 + 37}$			Cols. 9, 10 and 11 are Cols. 3, 4 and 5 multiplied by factor $\frac{B-47}{760} \times \frac{273}{273 + 37}$			Col. 12 = Col. 9 x 1.429	Col. 13 = Col. 10 x 1.293	Col. 14 = Col. 9 + Col. 10

(1) It is suggested that the overall instrumental tolerance of the demand valve at any altitude should not exceed 0.5 liters, STPD (± 0.25 liters from mean) on basis of 10 L./min. ventilation measured at B. 37° C. sat. However, if possible, the tolerance should be limited to 0.3 liters, STPD (± 0.15 liters from mean).
(2) At lower altitudes the initial proportions of oxygen may vary between the sea level (or possibly the 2,500 foot level) and the 5,000 or possibly 6,000 foot level.
(3) On the lower limit of tolerance the air inlet must always completely close at 33,000 feet to give 100% oxygen. This is necessary to maintain a normal sea level concentration of 149.3 mm. oxygen in the inspired air, saturated with moisture at 37° C.
(4) On the upper limit of tolerance the air inlet must close at 29,000 feet; preferably it should close at 30,000 or 31,000 feet.
(5) On chart XII-13 the vertical hatched areas along the oxygen and air requirements when measured volumetrically at 760, 0° C., dry, indicate the extreme limits of tolerance. The values for other methods of expression, of course, can be readily calculated.

Table 2 G e
August 1943
Walter M. Boothby

OXYGEN REQUIRED TO MAINTAIN IN INSPIRED AIR B. 37° C. SAT. THE EQUIVALENT PRESSURE EXISTING AT SEA LEVEL OF 149.3 MM.

Mayo Aero Medical Unit
Rochester, Minnesota

Altitude: Elevation	Altitude: Bar. Pres.	Total O_2 in Insp. Mix., Dry, to maintain in Tracheal Air, Sat. pO_2 = 149.3 mm.		O_2 added per Liter Insp. Mix. Both measured at B. 37° C. Sat.		O_2 Used by Aviator from Tank. The O_2 measured at 760, 0° C. Dry. The respiration measured at B. 37° C. Sat. For each liter resp.	Quiet: Breathing 10 L./min.	Working: Breathing 20 L./min.	Working: Breathing 30 L./min.
Feet	mm.	mm.	Per cent	Liters	Per cent	Liters	Liters	Liters	Liters
0	760	159.1	20.93	0	0	0	0	0	0
5,000	632	161.3	25.52	0.058	5.8	0.0393	0.4	0.8	1.2
10,000	523	164.8	31.36	0.132	13.2	0.0728	0.7	1.4	2.1
15,000	429	167.7	39.09	0.229	22.9	0.1014	1.0	2.0	3.0
20,000	349	172.6	49.46	0.360	36.0	0.1260	1.3	2.6	3.9
25,000	282	179.2	63.55	0.539	53.9	0.1468	1.5	3.0	4.5
30,000	226	188.6	83.45	0.790	79.0	0.1638	1.6	3.2	4.8
32,934	197	196.0	99.49	0.994	99.4	0.1728	1.7	3.4	5.1
33,000	196	196.3	100.20	1.002	100.2	0.1730	1.7	3.4	5.1
		Above this altitude an oxygen pressure of 149.3 mm. cannot be maintained in the inspired air because total barometric pressure is insufficient as there is 47 mm. pressure of water vapor at 37° C.							
35,000	179		100	1.0	100	0.1530	1.5	3.0	4.5
40,000	141		100	1.0	100	0.1090	1.1	2.2	3.3
42,000	128		100	1.0	100	0.0939	0.9	1.9	2.8

Table 2 G (a)

August 1943

OXYGEN REQUIRED TO MAINTAIN IN INSPIRED AIR B. 37° C. SAT.
THE EQUIVALENT PRESSURE EXISTING AT
5,000 FEET OF 122.5 MM.

Mayo Aero Medical Unit
Rochester, Minn.

Altitude: Elev-ation	Altitude: Bar. Pres.	Total O_2 in Insp. Mix., Dry, to maintain in Tracheal Air, Sat. pO_2 = 122.5 mm.		O_2 added per Liter Insp. Mix. Both measured at B. 37° C. Sat.		O_2 Used by Aviator from Tank. The O_2 measured at 760, 0° C. Dry. The respiration measured at B. 37° C. Sat.: For each liter resp.	Quiet: Breathing 10 L./min.	Working: Breathing 20 L./min.	Working: Breathing 30 L./min.
Feet	mm.	mm.	Per cent	Liters	Per cent	Liters	Liters	Liters	Liters
0	760	—	—	—	—	—	—	—	—
5,000	632	132.3	20.93	0	0	0	0	0	0
10,000	523	134.6	25.74	0.061	6.1	0.0336	0.3	0.6	0.9
15,000	429	137.6	32.07	0.141	14.1	0.0624	0.6	1.2	1.8
20,000	349	141.6	40.57	0.248	24.8	0.0868	0.9	1.8	2.7
25,000	282	147.0	52.13	0.394	39.4	0.1073	1.1	2.2	3.3
30,000	226	154.7	68.45	0.601	60.1	0.1246	1.2	2.4	3.6
33,000	196	161.1	82.19	0.775	77.5	0.1338	1.3	2.6	3.9
35,000	179	166.1	92.79	0.909	90.9	0.1391	1.4	2.8	4.2
36,000	170	169.3	99.59	0.995	99.5	0.1418	1.4	2.8	4.2
36,170	169	169.7	100.41	1.005	100.5	0.1420	1.4	2.8	4.2
Above this altitude an oxygen pressure of 122.5 mm. cannot be maintained in the inspired air because total barometric pressure is insufficient as there is 47 mm. pressure of water vapor at 37° C.									
37,000	162		100	1.0	100	0.1332	1.3	2.6	3.9
40,000	141		100	1.0	100	0.1090	1.1	2.2	3.3
42,000	128		100	1.0	100	0.0939	0.9	1.9	2.8

Table 2 G (b)
August 1943

OXYGEN REQUIRED TO MAINTAIN IN INSPIRED AIR B. 37° C. SAT.
THE EQUIVALENT PRESSURE EXISTING AT
6,000 FEET OF 117.7 MM.

Mayo Aero Medical Unit
Rochester, Minnesota

Altitude		Total O_2 in Insp. Mix., Dry, to maintain in Tracheal Air, Sat. pO_2 = 117.7 mm.		O_2 added per Liter Insp. Mix. Both measured at B. 37° C. Sat.		O_2 Used by Aviator from Tank. The O_2 measured at 760, 0° C. Dry. The respiration measured at B. 37° C. Sat.			
						For each liter resp.	Quiet	Working	
Elevation	Bar. Pres.						Breathing 10 L./min.	Breathing 20 L./min.	Breathing 30 L./min.
Feet	mm.	mm.	Per cent	Liters	Per cent	Liters	Liters	Liters	Liters
0	760	--	--	--	--	--	--	--	--
6,000	609	127.5	20.94	0	0	0	0	0	0
10,000	523	129.3	24.72	0.048	4.8	0.0265	0.3	0.6	0.9
15,000	429	132.2	30.82	0.125	12.5	0.0553	0.6	1.2	1.8
20,000	349	136.1	39.00	0.228	22.8	0.0798	0.8	1.6	2.4
25,000	282	141.2	50.07	0.369	36.9	0.1005	1.0	2.0	3.0
30,000	226	148.7	65.80	0.567	56.7	0.1176	1.2	2.4	3.6
33,000	196	154.8	78.98	0.734	73.4	0.1268	1.3	2.6	3.9
35,000	179	159.6	89.16	0.863	86.3	0.1320	1.3	2.6	3.9
36,000	170	162.7	95.71	0.945	94.5	0.1347	1.4	2.8	4.2
36,651	165	164.5	99.70	0.997	99.7	0.1364	1.4	2.8	4.2
36,799	164	165.0	100.61	1.007	100.7	0.1364	1.4	2.8	4.2
		Above this altitude an oxygen pressure of 117.7 mm. cannot be maintained in the inspired air because total barometric pressure is insufficient as there is 47 mm. pressure of water vapor at 37° C.							
37,000	162		100	1.0	100	0.1332	1.3	2.6	3.9
40,000	141		100	1.0	100	0.1090	1.1	2.2	3.3
42,000	128		100	1.0	100	0.0939	0.9	1.9	2.8

13

Table 2 G (c)

August 1943

EXAMPLE OF CALCULATION

Sea Level Requirement

Mayo Aero Medical Unit

STPD = Standard temperature, 0° C., and pressure, 760 mm., dry.
760 mm. = Barometric pressure at sea level.
47 mm. = Pressure of water vapor in saturated air at body temperature of 37° C.
Sat. = Air saturated with water vapor.
B = Ambient barometric pressure.
0.2094 = Per cent oxygen in air, dry.
0.7906 = Per cent nitrogen and other gases in air, dry.
T = Tracheal air = Inspired mixture at B. 37° C., sat. = condition of gases in body.
V_T = Volume inspired mixture measured at B. 37° C. sat.
TPO_2 = Pressure of oxygen desired in tracheal air.
For sea level equivalent = (760-47) 0.2094 = 149.3 mm.
" 5,000 ft. " = (632-47) 0.2094 = 122.5 mm.
" 6,000 ft. " = (609-47) 0.2094 = 117.7 mm.
AVO_2 = Volume oxygen measured at B. 37° C. sat. added to inspired mixture.
$AVO_{2_{STPD}}$ = Volume oxygen, STPD, added to inspired mixture.

For sea level equivalent:

$$AVO_2 = \frac{149.3 - 0.2094\ (B-47)}{0.7906\ (B-47)} \times V_T$$

$$AVO_2 = \frac{149.3}{0.7906\ (B-47)} - \frac{0.2094\ (B-47)}{0.7906\ (B-47)} \times 1, \text{ where } V_T = 1 \text{ liter.}$$

$$AVO_2 = \frac{188.844}{B-47} - .265$$

Therefore at 15,000 feet:

$$AVO_2 = \frac{188.844}{429-47} - .265 = 0.229 \text{ L. added per liter ventilation}$$
$$= 22.9\% \text{ as both measured at B, } 37^\circ \text{ C, sat.}$$

$$AVO_{2_{STPD}} = 0.229 \times \frac{429-47}{760} \times \frac{273}{273 + 37} = 0.1014 \text{ L. oxygen, 760, } 0^\circ \text{ C. dry.}$$

V_T = 10 L. per minute when the aviator is sitting quietly (B. 37° C. sat.).
= 20 L. " " " " " " doing light work " " " "
= 30 L. " " " " " " " fairly heavy work (B. 37° C. sat.).

IO_2 = Amount of oxygen in inspired mixture dry consisting of

(a) the oxygen in air, and
(b) the oxygen added necessary to maintain the desired oxygen equivalent.

$$PIO_2 = 149.3 \times \frac{429}{429-47} = 167.7 \text{ mm.}$$

$$\%IO_2 = \frac{167.7}{429} \times 100 = 39.09\%.$$

Table 2 G (d)
August 1943

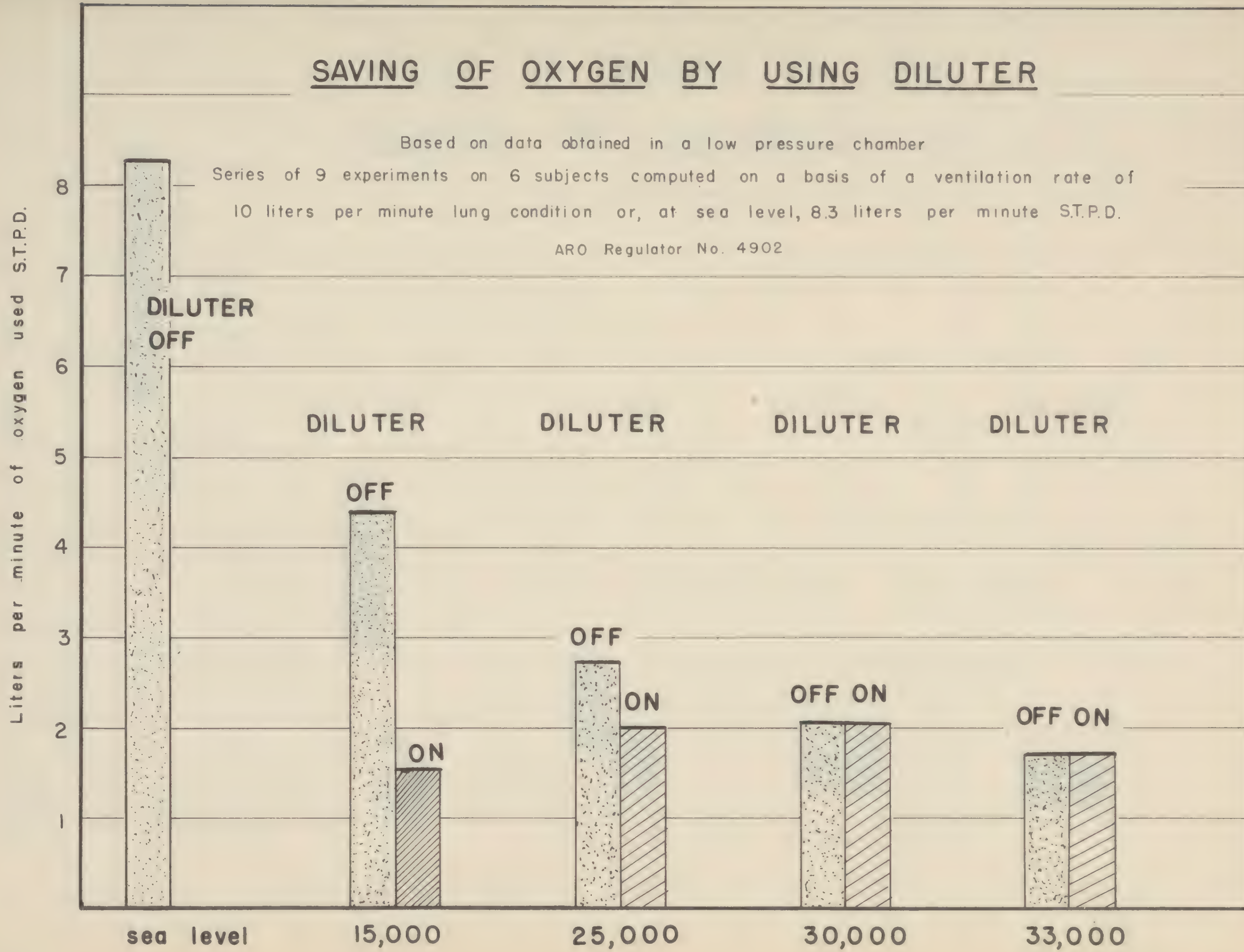
OXYGEN REQUIRED TO MAINTAIN IN INSPIRED AIR B. 37° C. SAT.
THE EQUIVALENT PRESSURE EXISTING AT
1,000 FEET OF 143.6 MM.

Mayo Aero Medical Unit
Rochester, Minnesota

Altitude: Elevation	Altitude: Bar. Pres.	Total O_2 in Insp. Mix., Dry, to maintain in Tracheal Air, Sat. pO_2 = 143.6 mm.		O_2 added per Liter Insp. Mix. Both measured at B. 37° C. Sat.		O_2 Used by Aviator from Tank. The O_2 measured at 760, 0° C. Dry. The respiration measured at B. 37° C. Sat. For each liter resp.	Quiet: Breathing 10 L./min.	Working: Breathing 20 L./min.	Working: Breathing 30 L./min.
Feet	mm.	mm.	Per cent	Liters	Per cent	Liters	Liters	Liters	Liters
0	760	153.4	20.94	0	0	0	0	0	0
5,000	632	155.1	24.51	0.045	4.5	0.0349	0.3	0.6	0.9
10,000	523	157.8	30.19	0.117	11.7	0.645	0.6	1.2	1.8
15,000	429	161.3	37.61	0.211	21.1	0.934	0.9	1.8	2.7
20,000	349	165.9	47.53	0.336	33.6	0.1176	1.2	2.4	3.6
25,000	282	172.3	61.33	0.508	50.8	0.1383	1.4	2.8	4.2
30,000	226	181.4	80.41	0.752	75.2	0.1556	1.6	3.2	4.8
32,000	206	186.1	90.43	0.939	93.9	0.1728	1.7	3.4	5.1
33,000	196	188.8	96.12	0.951	95.1	0.1647	1.7	3.4	5.1
33,650	191	190.5	100.00	1.000	100.0	0.1664	1.7	3.4	5.1
Above this altitude an oxygen pressure of 143.6 mm. cannot be maintained in the inspired air because total barometric pressure is insufficient as there is 47 mm. pressure of water vapor at 37° C.									
35,000	179		100.0	1.00	100.0	0.1530			
40,000	141		100.0	1.00	100.0	0.1089			
42,000	128		100.0	1.00	100.0	0.0939			

Table 2 G (f)

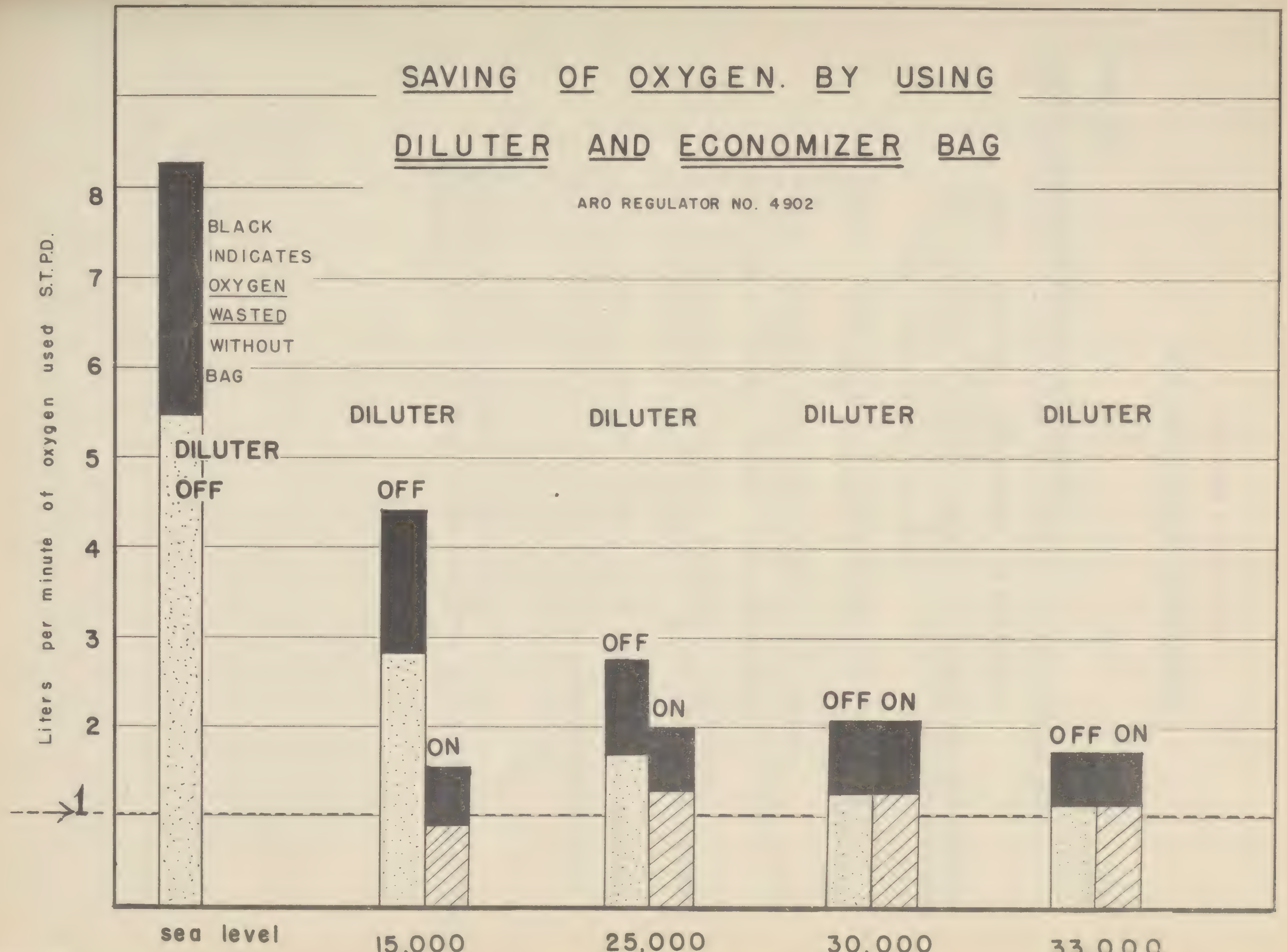
January 1944



XVIII-1 A

July 1943

W. M. Boothby



XVIII-1B

July 1943

MAYO AERO MEDICAL UNIT

DATA FROM HIGH ALTITUDE LABORATORY

Group III

PERCENT SATURATION HEMOGLOBIN DETERMINED BY
(a) Van Slyke blood gas analysis, (b) oximeter and (c) alveolar pO2

(1) III-10f March 1943, W.M.Boothby and R.F.Rushmer.
  (a) Calibration oximeter.
  (b) Comparison of oximeter reading and alveolar pO2 when oximeter set at 100% on oxygen it is found hemoglobin is 97% saturated when subject is breathing air.

(2) III-10g March 1943, W.M.Boothby and F.J.Robinson.
Same as in (1) except conditions of experiment slightly different.

(3) III-10h May 1943, replotted July 1945, W.M.Boothby.
The data of (1) and (2) replotted to show direct correlation percent saturation by oximeter against barometric pressure.

(4) III-10k May 1943 data replotted April 1946, W.M.Boothby.
The averages of data in (3) are plotted together with data from Naval Medical Research Institute, Bethesda.

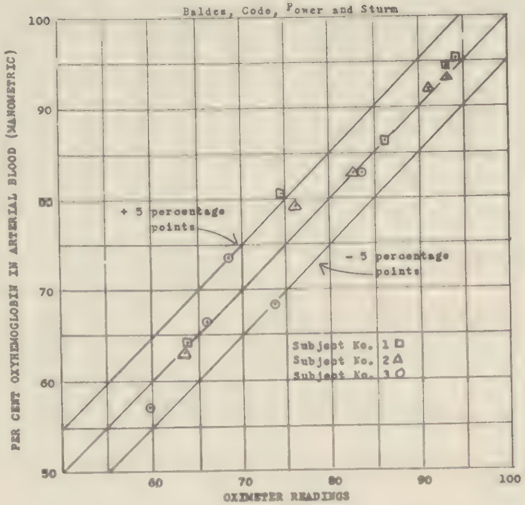
(5) III-8ca February 1943 replotted April 1, 1943 and again July 1946.
M.H.Power, J.P.Marbarger and C.B.Taylor.
Arterial hemoglobin saturation by blood gas compared with oximeter at high altitudes with and without positive pressure.

(6) III-8c February 1943, replotted July, 1946.
M.H.Power, J.P.Marbarger and C.B.Taylor.
Mayo Aero Medical Data and Wright Field data with and without positive pressure.

COMPARISON OF OXIMETER READINGS AND ALVEOLAR OXYGEN PRESSURES

CALIBRATION OF OXIMETER

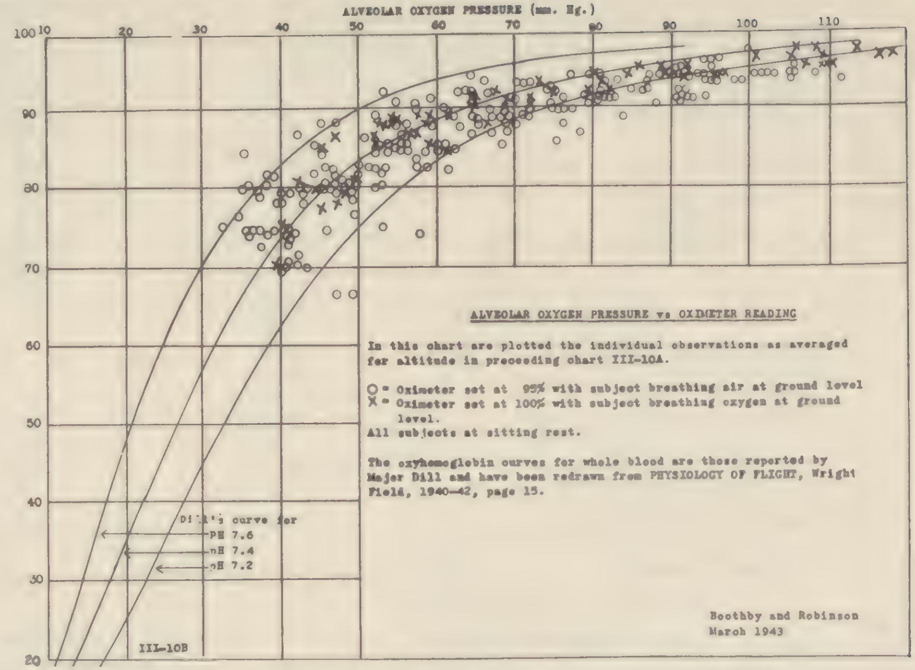
Baldes, Code, Power and Sturm



This chart shows the calibration data on the oximeter used in this laboratory (Coleman Model 17, 5769) obtained by analysis of the oxygen capacity and content of the arterial blood by the manometric technic of Van Slyke and Neill. Subjects at lying rest.

II -8A

Boothby and Robinson March, 1943.



ALVEOLAR OXYGEN PRESSURE vs OXIMETER READING

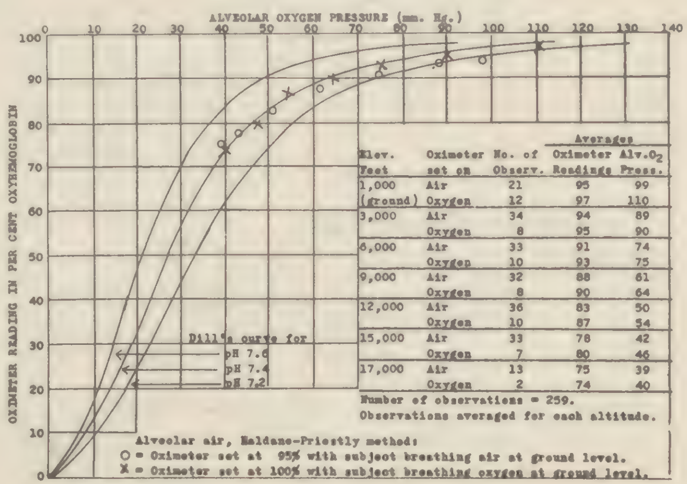
In this chart are plotted the individual observations as averaged for altitude in preceeding chart III-10A.

○ = Oximeter set at 95% with subject breathing air at ground level
X = Oximeter set at 100% with subject breathing oxygen at ground level.

All subjects at sitting rest.

The oxyhemoglobin curves for whole blood are those reported by Major Dill and have been redrawn from PHYSIOLOGY OF FLIGHT, Wright Field, 1940-42, page 15.

Boothby and Robinson
March 1943



Elev. Feet	Oximeter set on	No. of Observ.	Averages: Oximeter Readings	Averages: Alv. O_2 Press.
1,000	Air	21	95	99
(ground)	Oxygen	12	97	110
3,000	Air	34	94	89
	Oxygen	8	95	90
6,000	Air	33	91	74
	Oxygen	10	93	75
9,000	Air	32	88	61
	Oxygen	8	90	64
12,000	Air	36	83	50
	Oxygen	10	87	54
15,000	Air	33	78	42
	Oxygen	7	80	46
17,000	Air	13	75	39
	Oxygen	2	74	40

Number of observations = 259.
Observations averaged for each altitude.

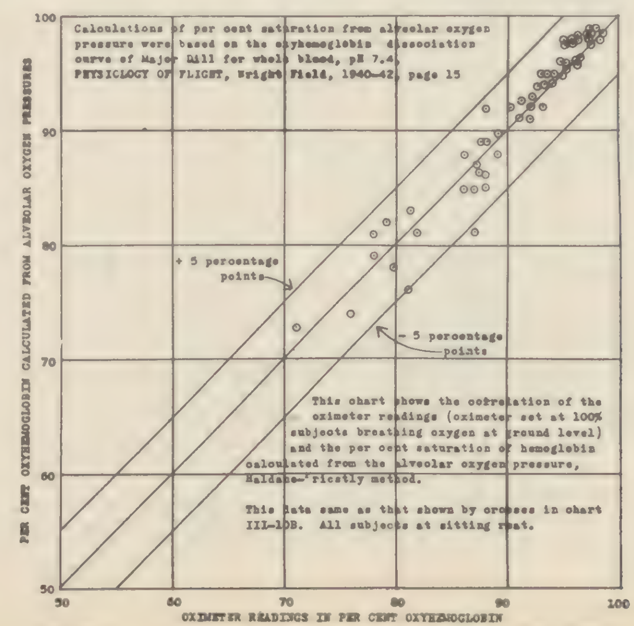
Alveolar air, Haldane-Priestly method:
○ = Oximeter set at 95% with subject breathing air at ground level.
X = Oximeter set at 100% with subject breathing oxygen at ground level.

The individual observations comprising the averages are shown in chart III-10B.
All subjects at sitting rest.

The oxyhemoglobin dissociation curves for whole blood are those reported by Major Dill and have been redrawn from PHYSIOLOGY OF FLIGHT, Wright Field, 1940-42, page 15.

III-10A

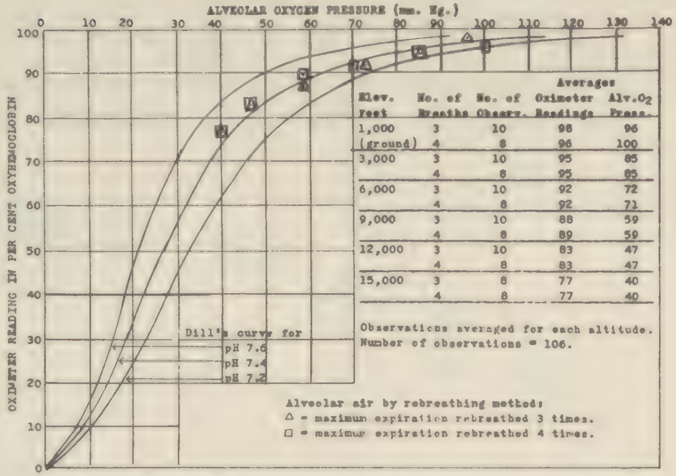
Boothby and Robinson March, 1943.



III-10Ba

Boothby and Robinson March 1943.

COMPARISON OF OXIMETER READINGS AND ALVEOLAR OXYGEN PRESSURES



Elev. Feet	No. of Breaths	No. of Observ.	Averages Oximeter Readings	Alv. O_2 Press.
1,000	3	10	98	96
(ground)	4	8	96	100
3,000	3	10	95	85
	4	8	95	85
6,000	3	10	92	72
	4	8	92	71
9,000	3	10	88	59
	4	8	89	59
12,000	3	10	83	47
	4	8	83	47
15,000	3	8	77	40
	4	8	77	40

Observations averaged for each altitude.
Number of observations = 106.

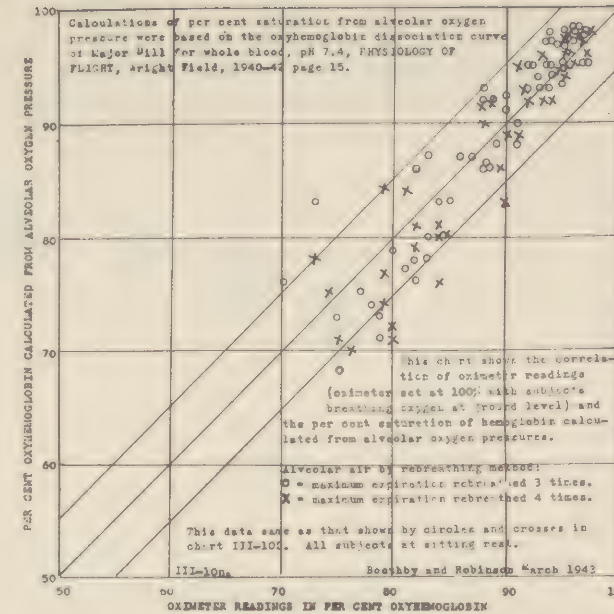
Alveolar air by rebreathing method:
△ = maximum expiration rebreathed 3 times.
□ = maximum expiration rebreathed 4 times.

Oximeter set at 100% with subject breathing oxygen at ground level. The individual observations comprising the averages are shown in chart III-10D. All subjects at sitting rest.

The oxyhemoglobin dissociation curves for whole blood are those reported by Major Dill and have been redrawn from PHYSIOLOGY OF FLIGHT, Wright Field, 1940-42, page 15.

Boothby and Robinson
March 1943

III-10C



Calculations of per cent saturation from alveolar oxygen pressure were based on the oxyhemoglobin dissociation curve of Major Dill for whole blood, pH 7.4, PHYSIOLOGY OF FLIGHT, Wright Field, 1940-42 page 15.

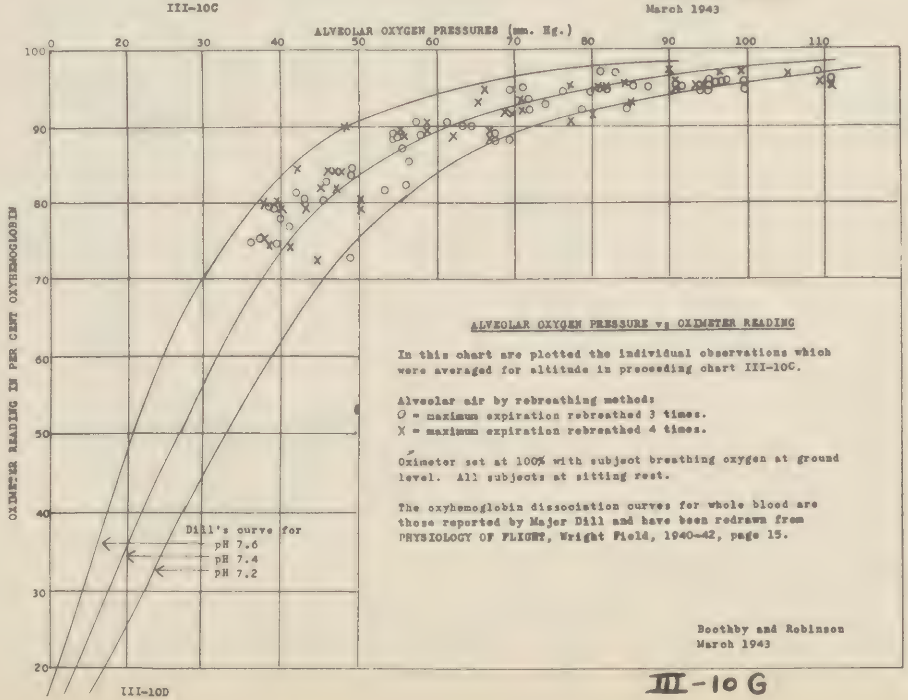
This chart shows the correlation of oximeter readings (oximeter set at 100% with subject's breathing oxygen at ground level) and the per cent saturation of hemoglobin calculated from alveolar oxygen pressures.

Alveolar air by rebreathing method:
O = maximum expiration rebreathed 3 times.
X = maximum expiration rebreathed 4 times.

This data same as that shown by circles and crosses in chart III-10D. All subjects at sitting rest.

III-10Da

Boothby and Robinson March 1943



ALVEOLAR OXYGEN PRESSURE vs OXIMETER READING

In this chart are plotted the individual observations which were averaged for altitude in preceeding chart III-10C.

Alveolar air by rebreathing method:
O = maximum expiration rebreathed 3 times.
X = maximum expiration rebreathed 4 times.

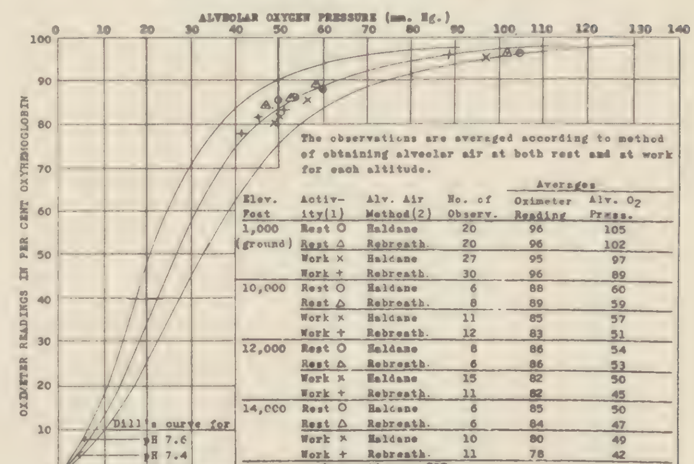
Oximeter set at 100% with subject breathing oxygen at ground level. All subjects at sitting rest.

The oxyhemoglobin dissociation curves for whole blood are those reported by Major Dill and have been redrawn from PHYSIOLOGY OF FLIGHT, Wright Field, 1940-42, page 15.

Boothby and Robinson
March 1943

III-10D

III-10 G



The observations are averaged according to method of obtaining alveolar air at both rest and at work for each altitude.

Elev. Feet	Activity(1)	Alv. Air Method(2)	No. of Observ.	Averages Oximeter Reading	Alv. O_2 Press.
1,000	Rest O	Haldane	20	96	105
(ground)	Rest △	Rebreath.	20	96	102
	Work ×	Haldane	27	95	97
	Work +	Rebreath.	30	96	89
10,000	Rest O	Haldane	6	88	60
	Rest △	Rebreath.	8	89	59
	Work ×	Haldane	11	85	57
	Work +	Rebreath.	12	83	51
12,000	Rest O	Haldane	8	86	54
	Rest △	Rebreath.	6	86	53
	Work ×	Haldane	15	82	50
	Work +	Rebreath.	11	82	45
14,000	Rest O	Haldane	6	85	50
	Rest △	Rebreath.	6	84	47
	Work ×	Haldane	10	80	49
	Work +	Rebreath.	11	78	42

Number of observations = 207.

(1) Rest - sitting in chair. Work - stepping onto 5 inch stool 16 times per minute with metronome set at 80 to obtain 5 beats to alternate legs used for elevation.
(2) Alveolar air methods: (a) Haldane-Priestly.
(b) Rebreathing method with single expiration rebreathed 3 times.

Oximeter set at 100% with subject breathing oxygen at ground level.
The oxygen dissociation curves for whole blood are those reported by Major Dill and have been redrawn from PHYSIOLOGY OF FLIGHT, Wright Field, 1940-42, page 15.

III-10E

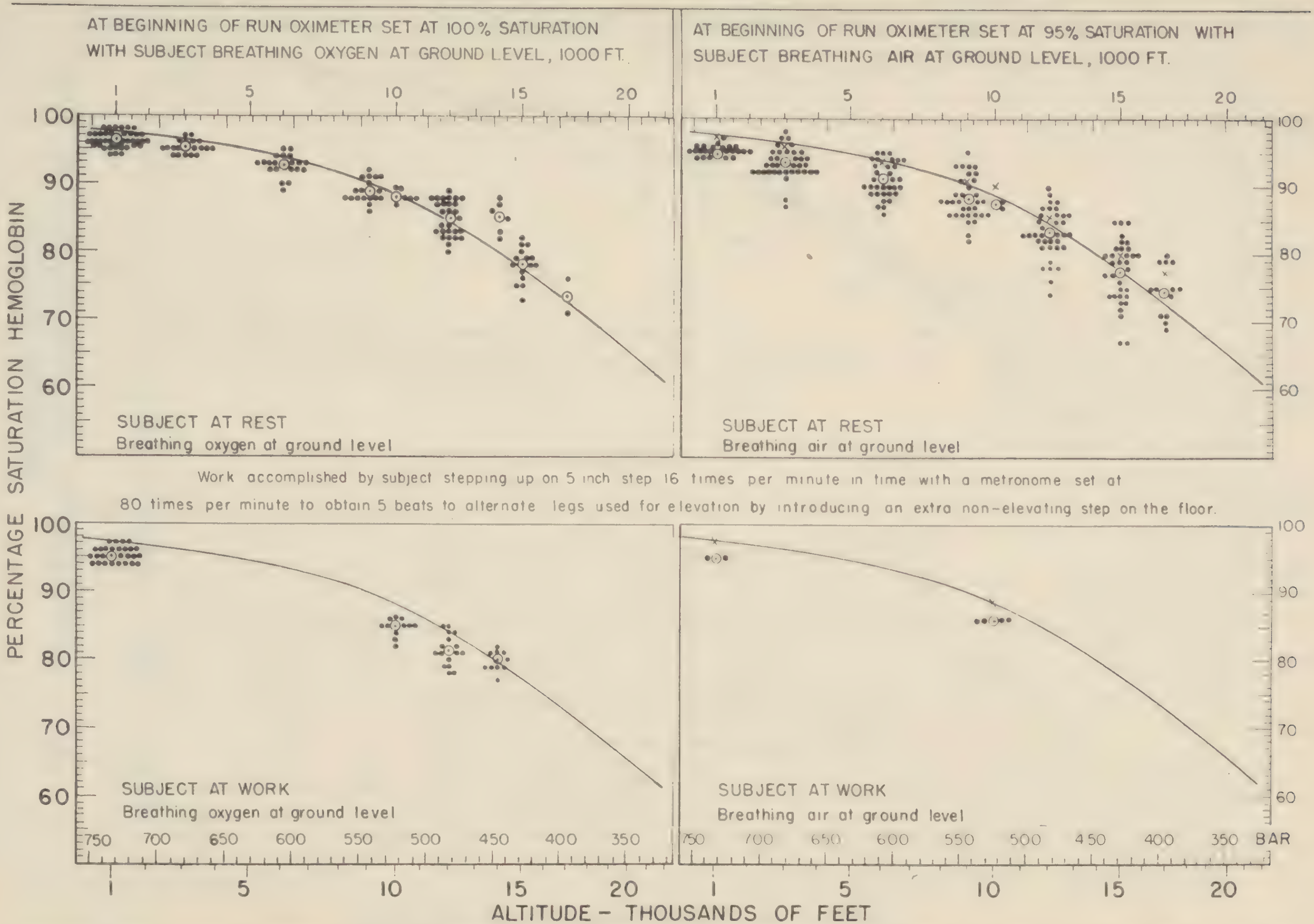
Boothby and Robinson
March 1943

PERCENT SATURATION HEMOGLOBIN PLOTTED AGAINST BAROMETRIC PRESSURE

○ AVERAGE OF ACTUAL OXIMETER OBSERVATIONS AT EACH ALTITUDE

• INDIVIDUAL OBSERVATIONS AND UNCORRECTED

× AVERAGE INCREASED 2.5 TO OBTAIN APPROXIMATE CORRECTION FOR ORIGINAL SETTING AT 95% INSTEAD OF 97% OR 98%



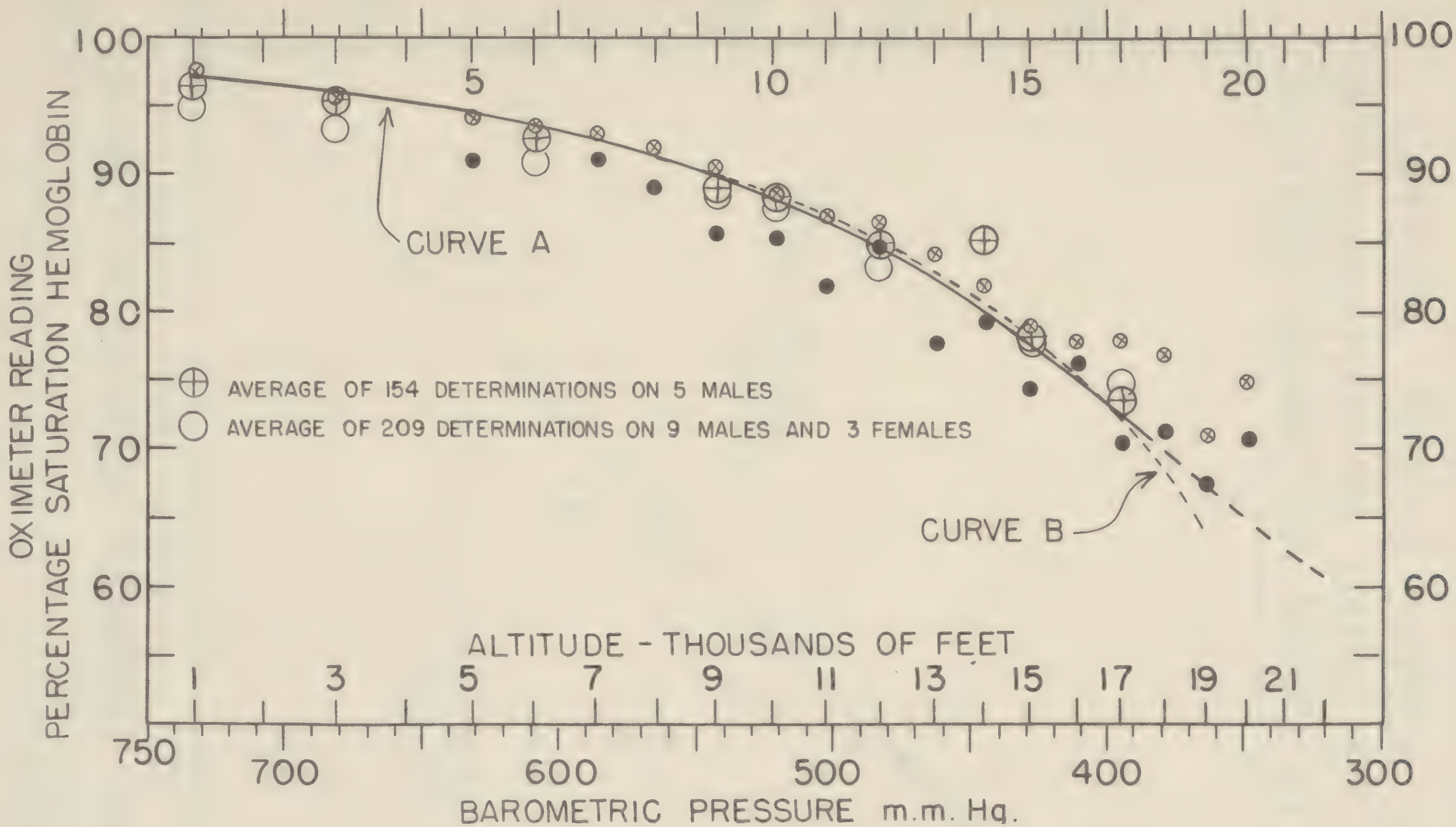
Smoothed curves obtained by reading; First the average alveolar oxygen pressure read from smooth curve A on chart I-6b, *Mayo Aero Medical Unit* (same as chart A-1 in *Handbook of Respiration on Data in Aviation* prepared by Subcommittee on Oxygen and Anoxia of CAM for CMR, OSRD.) Second the corresponding percent saturation Hemoglobin read from Dills Oxygen Dissociation Curve, pH 7.4

(Fig. 9 Physiology of Flight 1940–1942, Wright Field, AAF.)

CHART III-10H   Replotting data of Boothby and Robinson, CAM Report No. 163, June 1943   W.M. Boothby, July 1945

MAYO AERO MEDICAL UNIT

AVERAGE PERCENT SATURATION HEMOGLOBIN - OXIMETER



Data from the Mayo Aero Medical Unit - 1943

⊕ Oximeter set at 100% - Subject breathing oxygen
○ Oximeter set at 95% - Subject breathing air

} Not over 10 minutes at progressively increasing altitudes

Curve A: Obtained by reading: First the average alveolar oxygen pressure read from smooth curve A, chart A-1, Handbook of Respiration, Subcommittee on Oxygen and Anoxia N.R.C. Second the corresponding percent saturation hemoglobin from Dill's dissociation curve, pH 7.4, Fig. 9 Physiology of Flight 1940-1942, Wright Field, AAF.

Data from the Naval Medical Research Institute, Bethesda

⊗ Less than 10 minutes at progressively increasing altitudes
● More than 15 minutes at progressively increasing altitudes (not over 30 minutes)

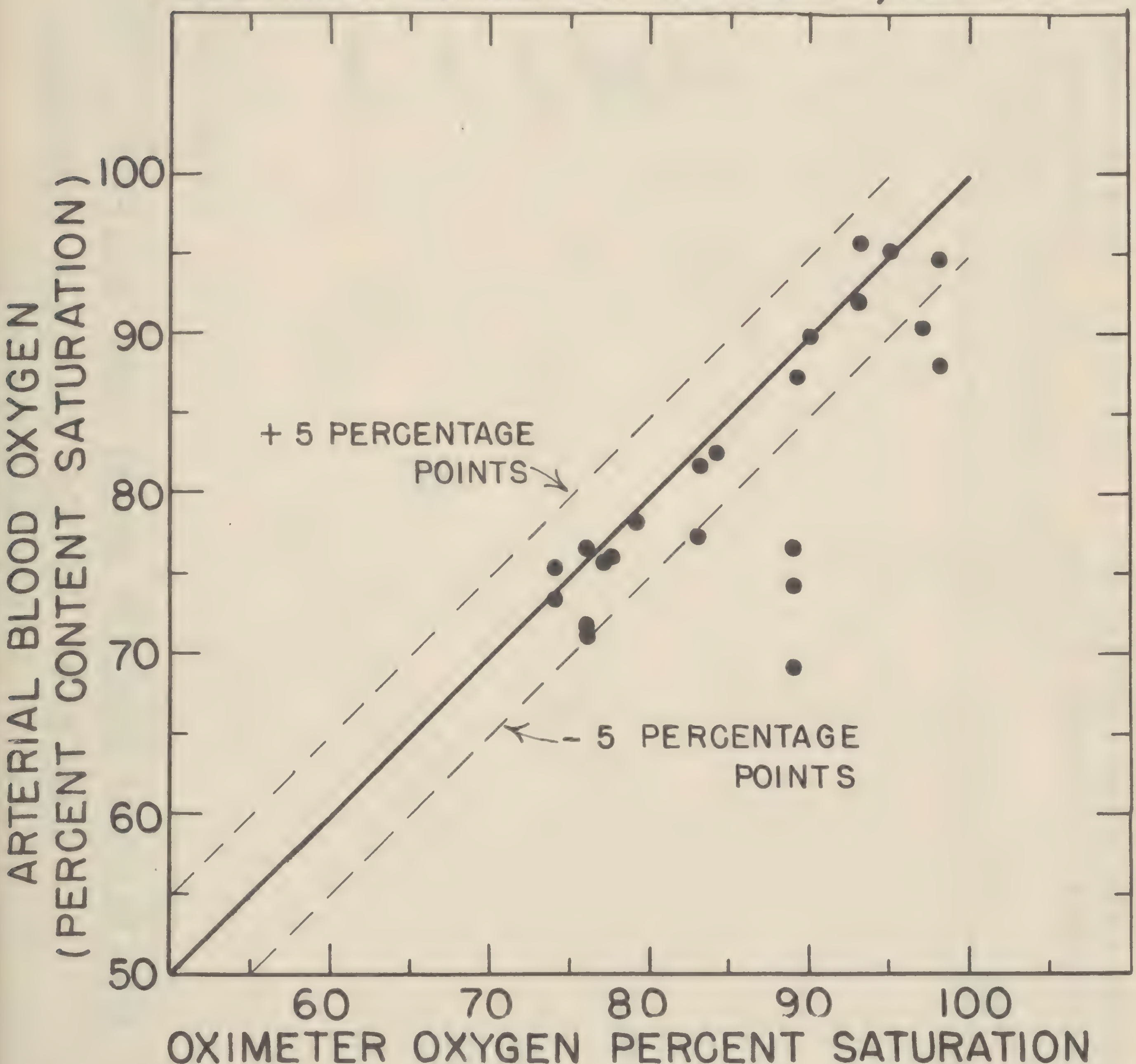
Curve B: chart B-4 in Handbook of Respiratory Data in Aviation, Subcommittee on Oxygen and Anoxia, N.R.C.

Chart III-10k

W. M. Boothby, April, 1946

MAYO AERO MEDICAL UNIT

ARTERIAL BLOOD OXYGEN CONTENT DETERMINATION VS OXIMETER READINGS COLEMAN OXIMETER-MODEL 17, NO. 5769

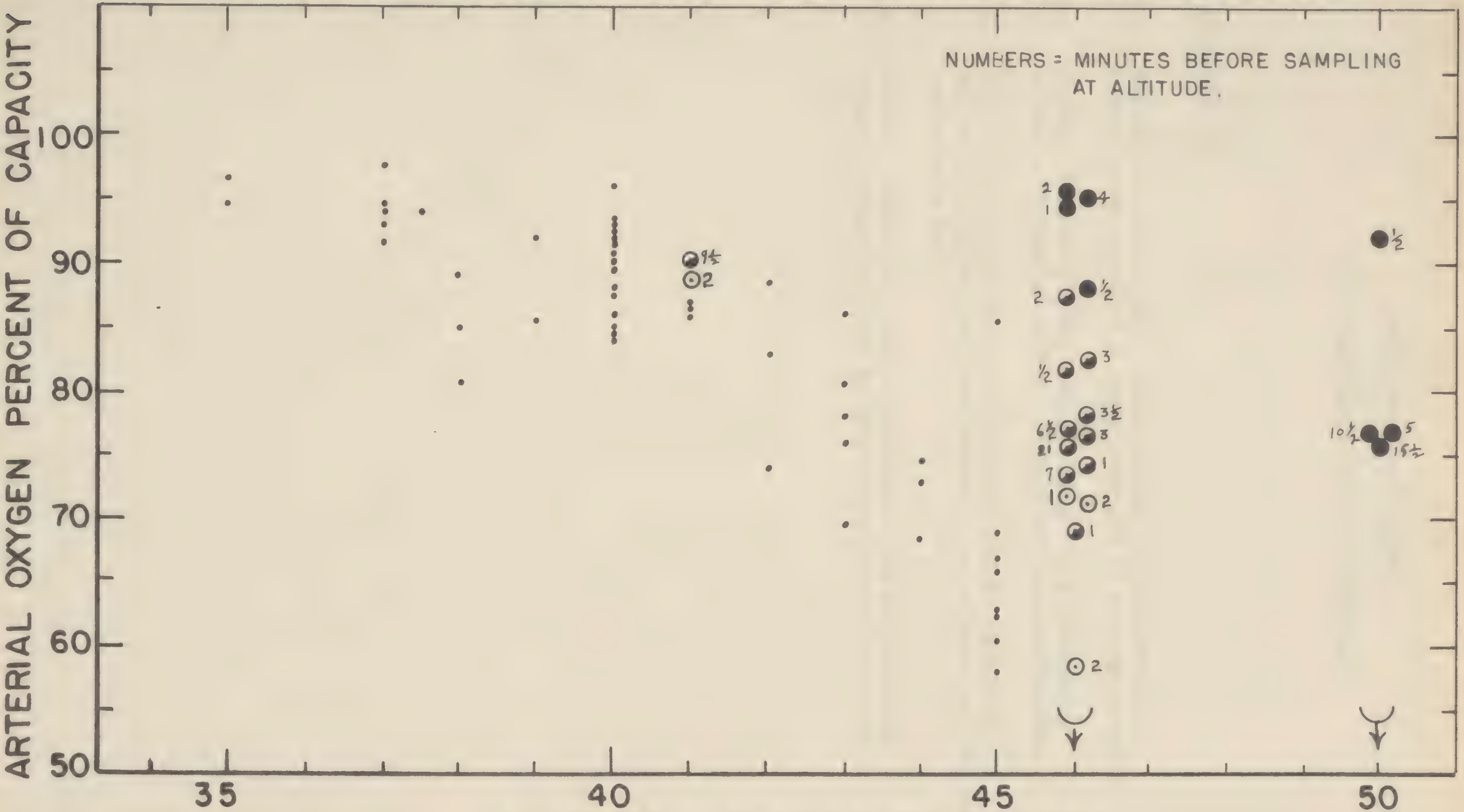


III - 8 Ca

Power, Taylor, Marbarger
March, 1943

MAYO AERO MEDICAL UNIT

ARTERIAL BLOOD OXYGEN CONTENT
BREATHING OXYGEN WITH AND WITHOUT PRESSURE



• No pressure - Physiology of Flight Wright Field, 1940-42, Fig. 8

○ No pressure

◐ 20 cm. water pressure

● 40-46 cm. water pressure

III-8-C

POWER, TAYLOR AND MARBARGER

MARCH, 1943

MAYO AERO MEDICAL UNIT

DATA FROM HIGH ALTITUDE LABORATORY

Group IV

VITAL CAPACITY

(1) XIX-2b September 1943, H.A.Robinson and F.J.Robinson
Method of measurement - Error produced by absorption of CO_2

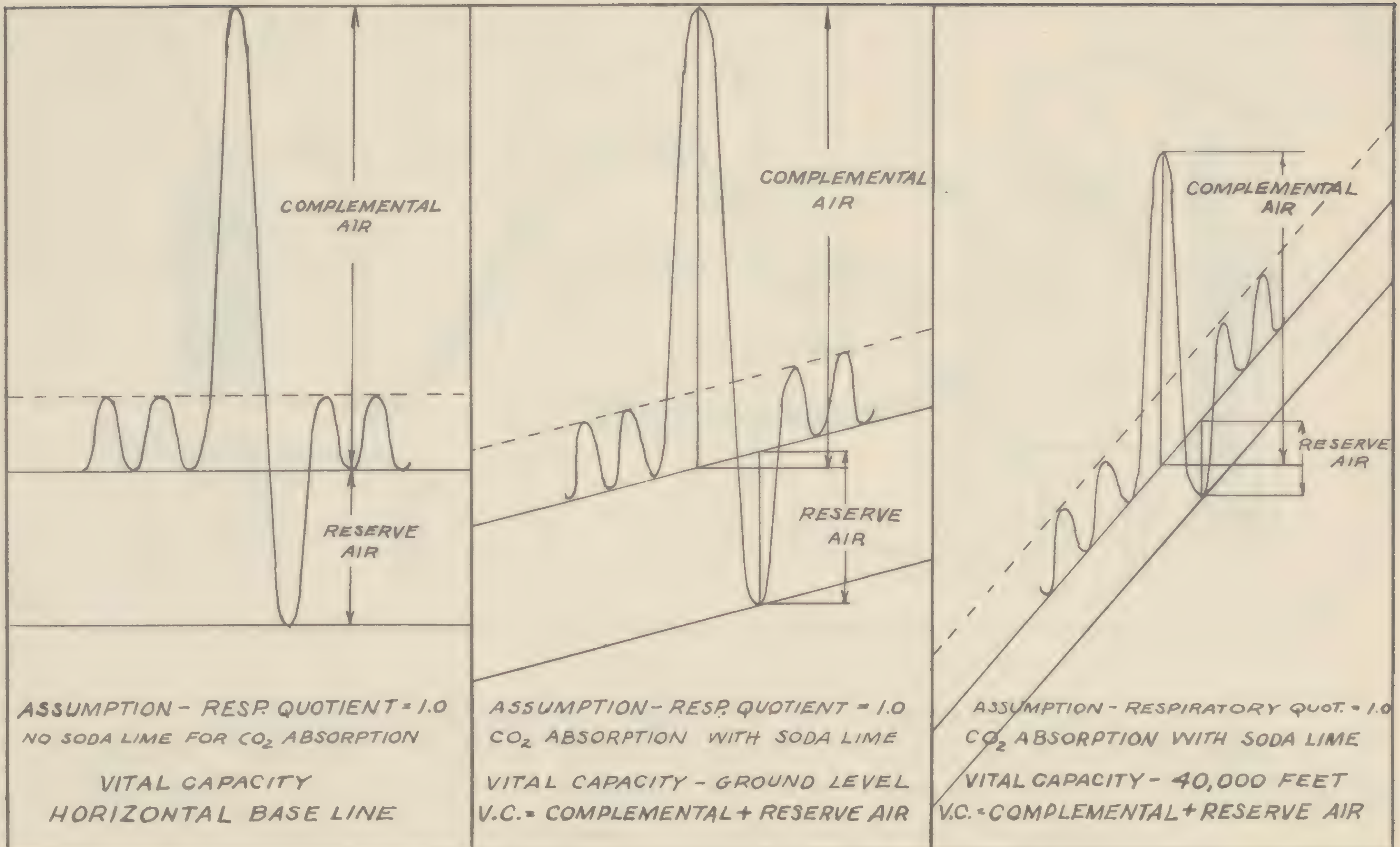
(2) XIX-2a September 1943, H.A.Robinson and F.J.Robinson
Method to determine effect of positive pressure breathing.

(3) XIX-2c September 1943, H.A.Robinson and F.J.Robinson
Effect of positive pressure breathing on relation of complimental and reserve air.

(4) XIX-2d September 1943, H.A.Robinson and F.J.Robinson
Error in vital capacity by absorption of CO_2 - Greater the higher the altitude.

MAYO AERO MEDICAL UNIT

VITAL CAPACITY
METHOD OF MEASUREMENT

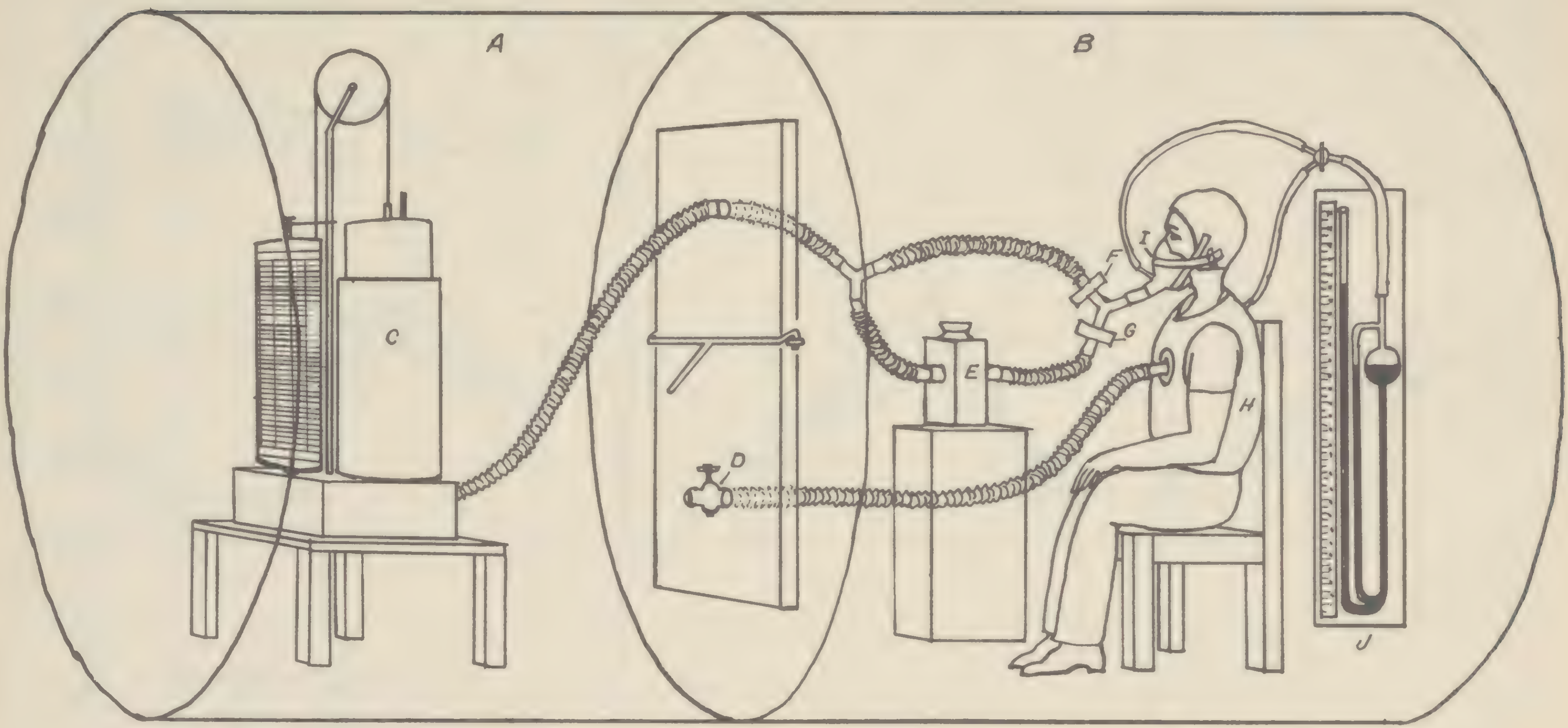


MAJ. H.A. ROBINSON, MC SEPT. 1943
F.J. ROBINSON, M.D.

XIX - 2 b APPENDIX FIG. II

MAYO AERO MEDICAL UNIT

APPENDIX FIG. I



SKETCH OF APPARATUS USED TO DETERMINE EFFECTS OF POSITIVE PRESSURE WITH AND WITHOUT CORRESPONDING COUNTER PRESSURE. PRESSURE, IN WATER CMS., OBTAINED BY DIFFERENTIAL IN THE TWO CHAMBERS

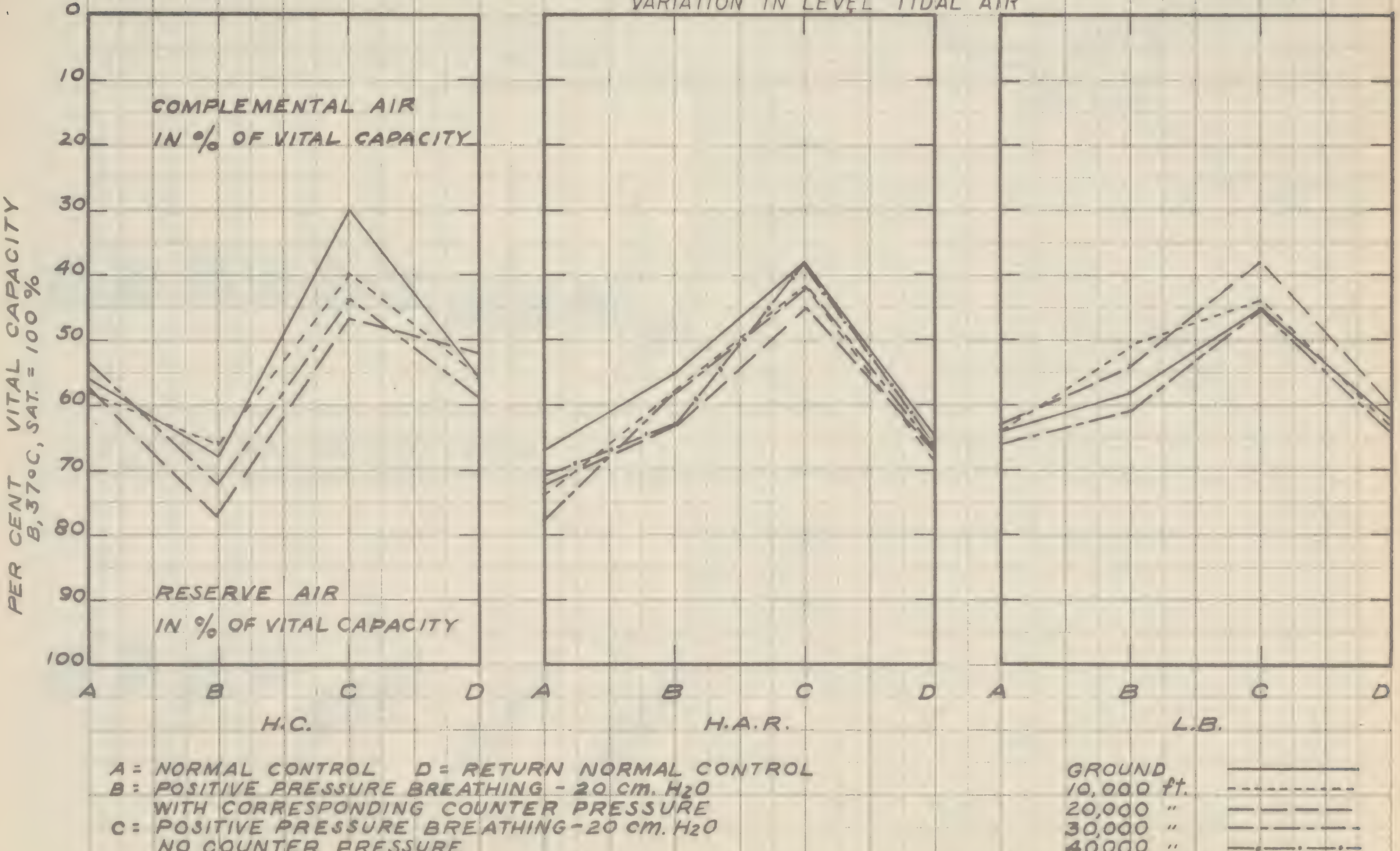
A. AIR LOCK B. MAIN CHAMBER C. BOOTHBY-COLLINS SPIROMETER
D. VALVE TO RELEASE COUNTER PRESSURE E. SODA LIME F. INSPIRATORY VALVE
G. EXPIRATORY VALVE H. PRESSURE BREATHING JACKET
I. PRESSURE BREATHING MASK J. WATER MANOMETER

MAJ. H.A. ROBINSON, MC SEPT 1943
F.J. ROBINSON, M.D.

Mayo Aero Medical Unit

EFFECTS OF POSITIVE PRESSURE BREATHING ON RELATION OF COMPLEMENTAL AND RESERVE AIR IN PER CENT OF VITAL CAPACITY AT ALTITUDES

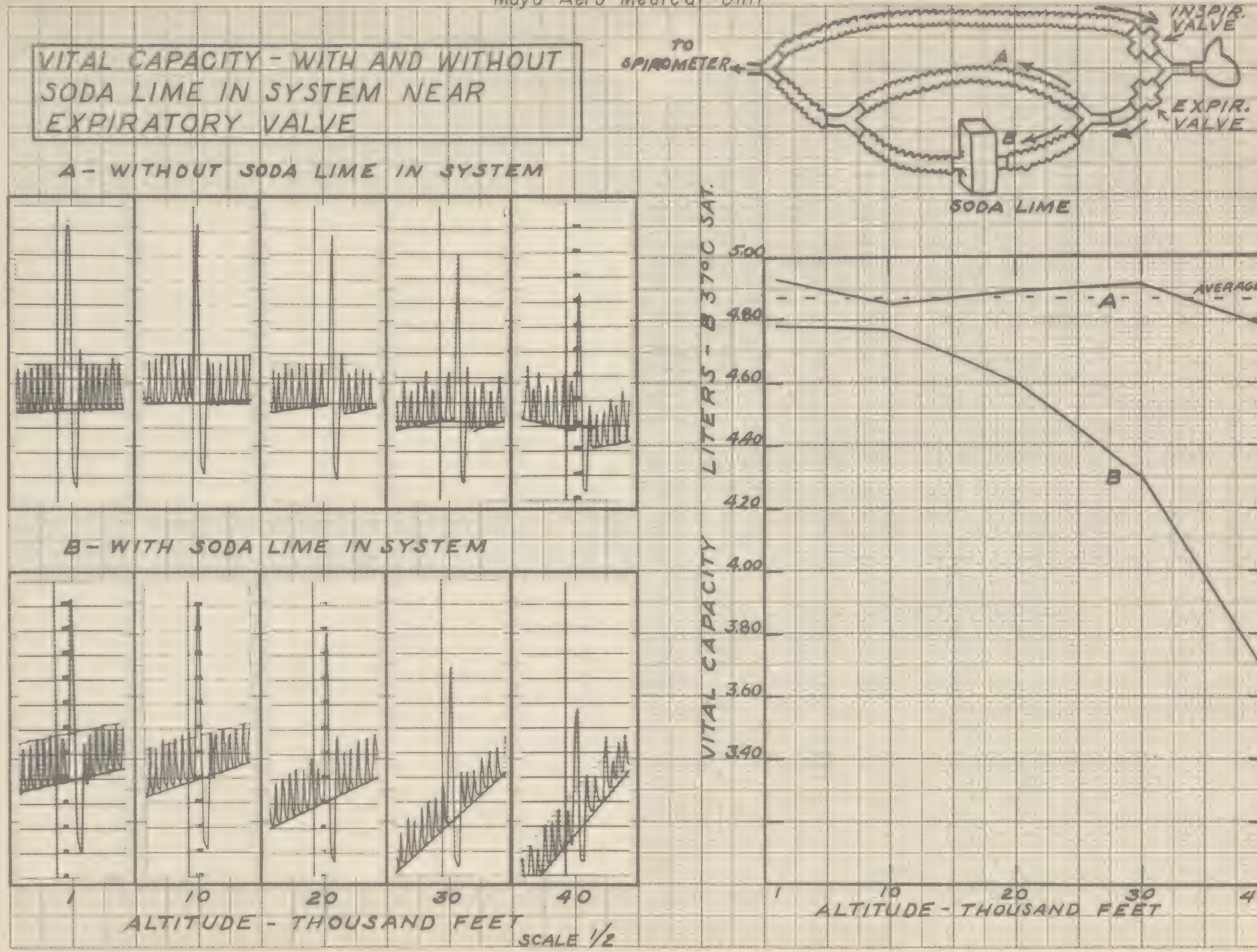
VARIATION IN LEVEL TIDAL AIR



XIX- 2 C

MAJ. H.A. ROBINSON, MC SEPT. '43 HR
F.J. ROBINSON, M.D.

APPENDIX FIG. III



XIX - 2d APPEND FIG. IV

MAJ. H.A. ROBINSON, MC SEPT. 1943
F.J. ROBINSON, MD

MAYO AERO MEDICAL UNIT

DATA FROM HIGH ALTITUDE LABORATORY

Group V

VOLUNTARY HYPERVENTILATION

(1) X-12(a,b,c,d.) November 1941, Redrawn 1944, W.M.Boothby, R.F.Rushmer and J. Wilson.
Graphic representation of data on 4 subjects. Ventilation rate, Respiration Rate, Oxygen Consumption, Alveolar and Expired Air R.Q., Alveolar pO_2, Alveolar pCO_2 and CO_2 deficit.

(2) X-10 November 1941, Redrawn 1944, R.F.Rushmer, J.Wilson and W.M.Boothby.
Variation of alveolar pCO_2 with ventilation rate.

(3) X-11 November 1941, Redrawn 1944, R.F.Rushmer, J.Wilson and W.M.Boothby.
Variation of alveolar pCO_2 with body deficit CO_2.

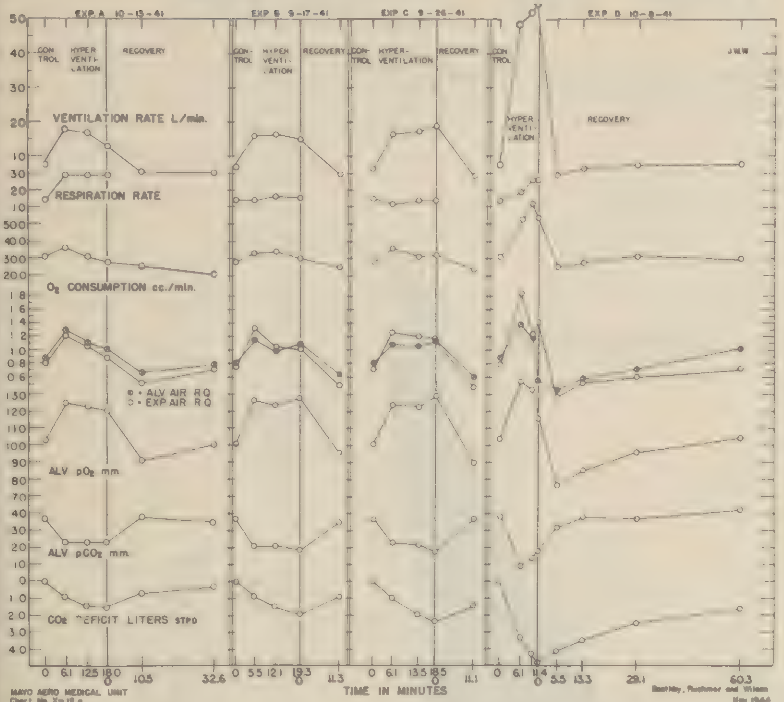
(4) X-13a October 1941, W.M.Boothby.
Respiratory curves on subject R.T.P. with notes.

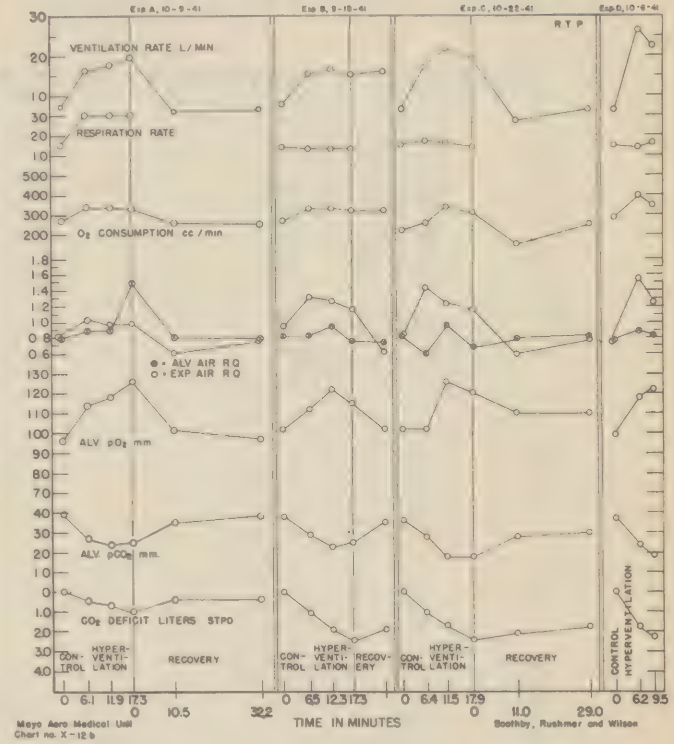
(5) X-13b October 1941, W.M.Boothby.
Respiratory curves on subject R.W.B. with notes.

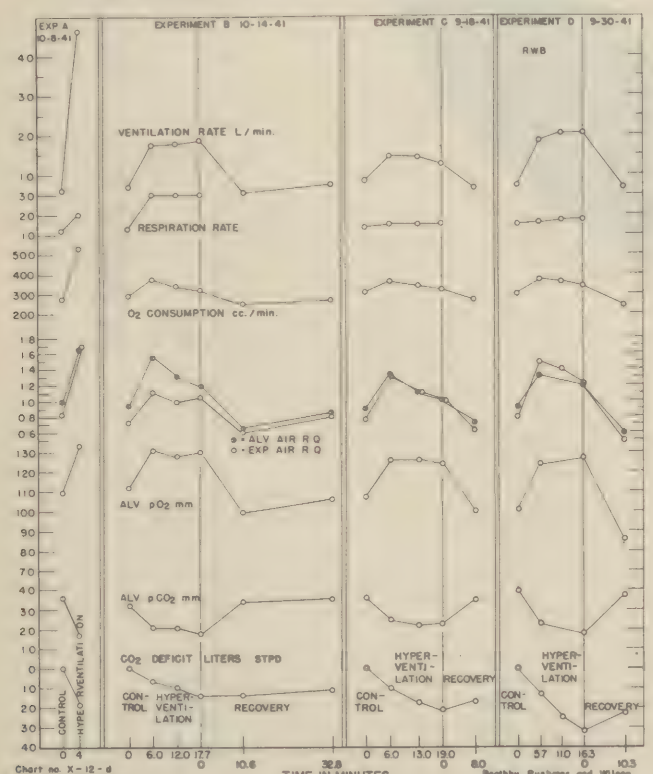
(6) X-13d October 1941, W.M.Boothby.
Respiratory curves on subject J.W.W. with notes.

VOLUNTARY HYPERVENTILATION

Graphic representation: on four subjects







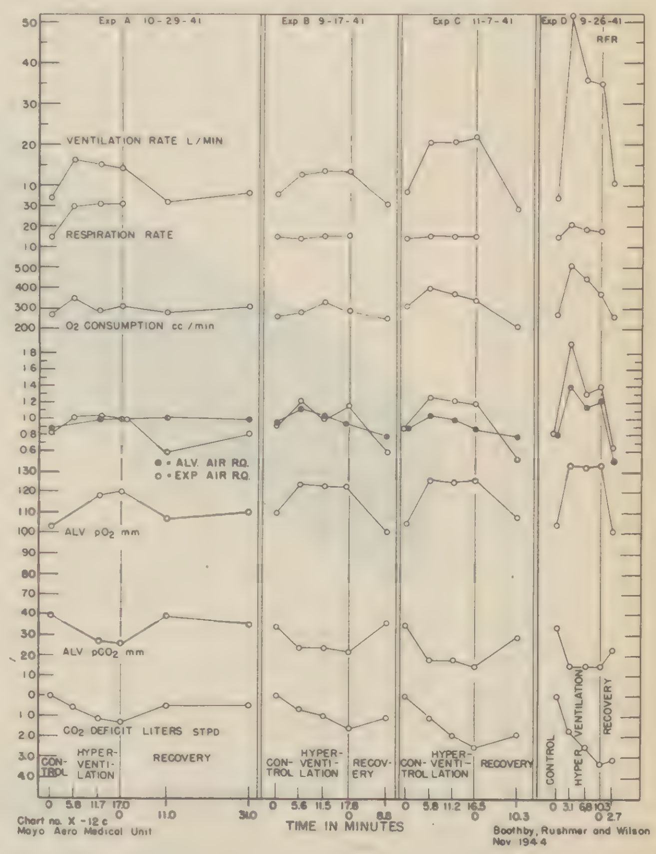
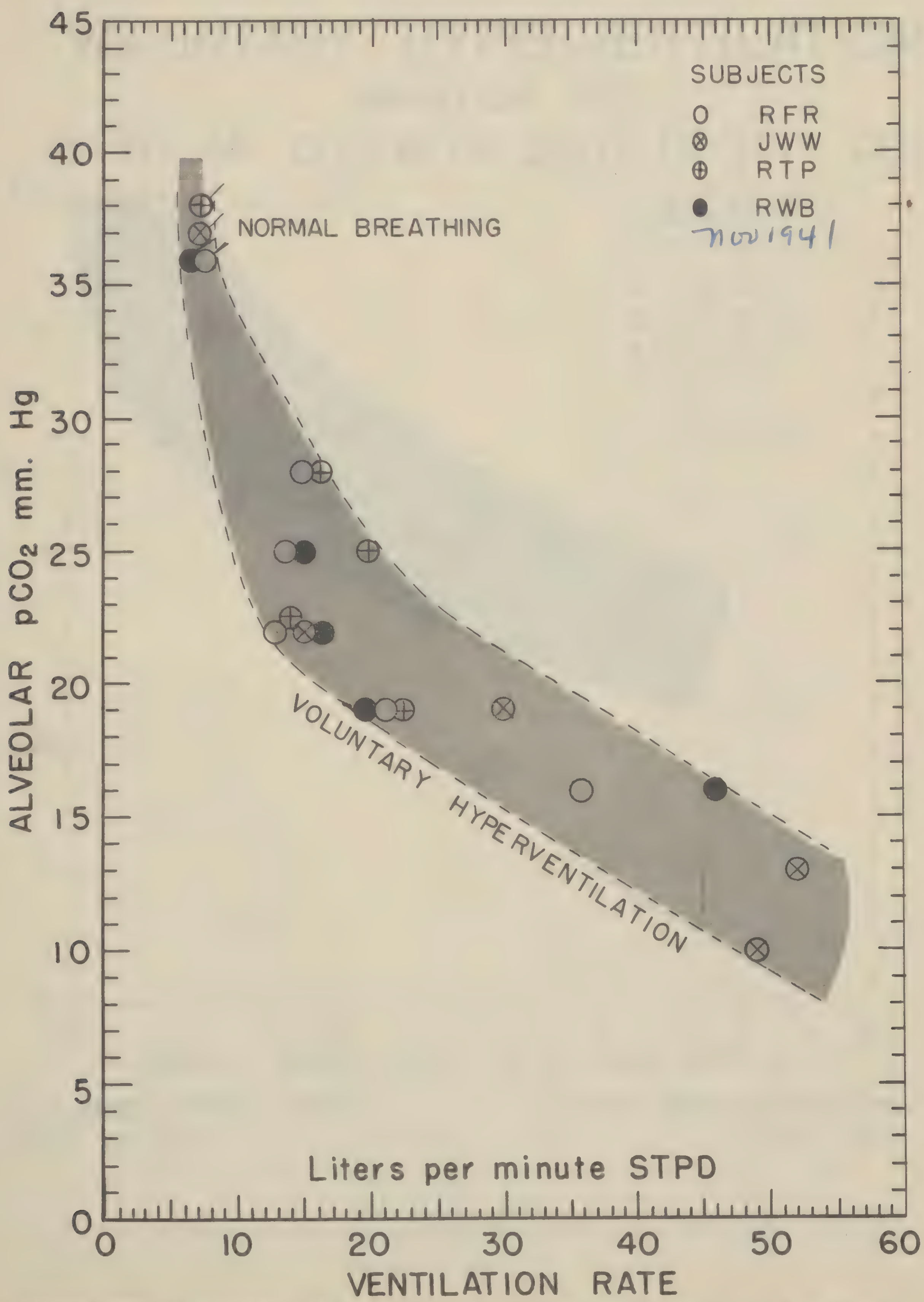


Chart no. X-12(a,b,c,d)
Mayo Aero Medical Unit

VOLUNTARY HYPERVENTILATION

VARIATION OF ALVEOLAR CO_2 WITH VENTILATION RATE

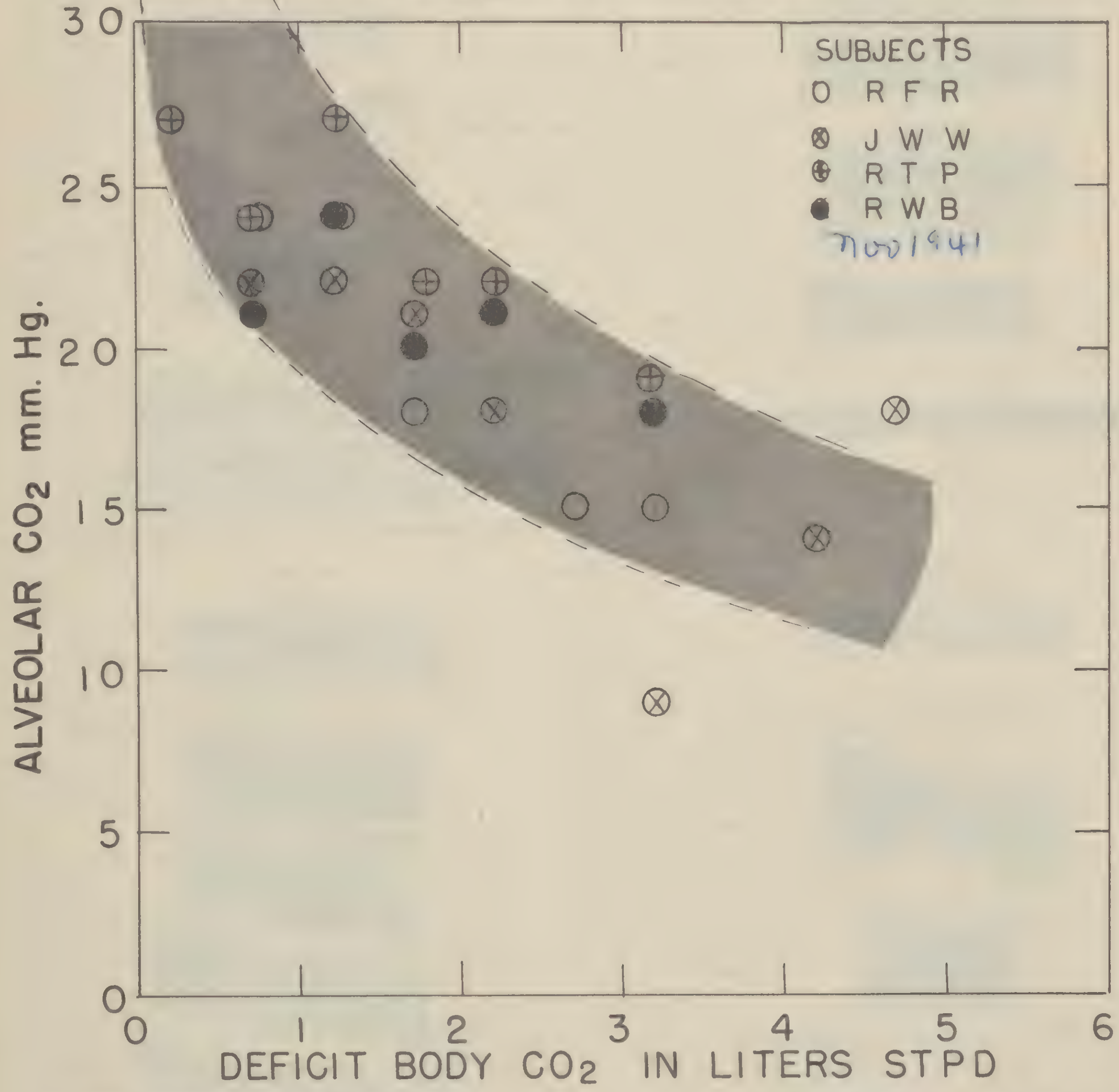


MAYO AERO MEDICAL UNIT
CHART NO. X - 10

Rushmer, Wilson and Boothby
OCT. 1944

VOLUNTARY HYPERVENTILATION

VARIATION OF ALVEOLAR CO_2 WITH BODY DEFICIT CO_2



MAYO AERO MEDICAL UNIT
CHART NO. X-11

Rushmer, Wilson and Boothby
Oct. 1944

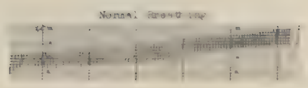
MAYO AERO MEDICAL UNIT

VOLUNTARY HYPERVENTILATION

Subject RTP

EXPERIMENT A   Oct. 9, 1941

Normal Breathing



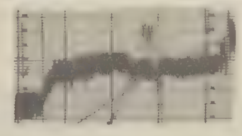
Hyperventilation for 17.3 minutes.
Ventilation rate: 2.5 times normal. Respiration rate: 2.0 times normal.

1st. Period

2nd. Period

(Upward trend due to leak around neck of subject as he was breathing inside coffin.)

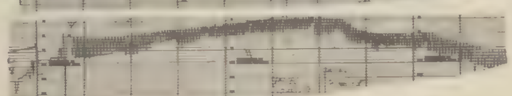
3rd. Period



Recovery

1st. Period

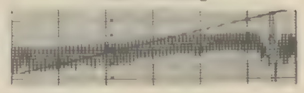
2nd. Period



No subjective symptoms produced and breathing was essentially normal after stopping hyperventilation.

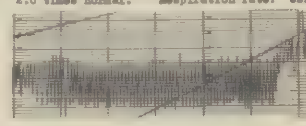
EXPERIMENT B   Sept. 18, 1941

Normal Breathing

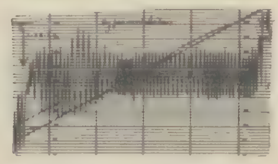


Hyperventilation for 17.3 minutes.
Ventilation rate: 2.0 times normal. Respiration rate: essentially normal.

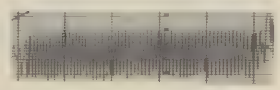
1st. Period



2nd. Period



3rd. Period

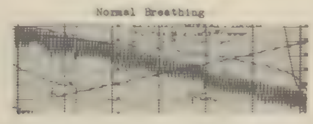


Recovery

No subjective symptoms noted. On stopping hyperventilation irregular breathing for 1 minute, quickly becoming normal.

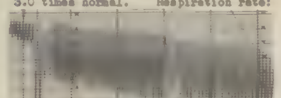
EXPERIMENT C   Oct. 22, 1941

Normal Breathing



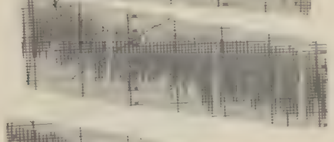
Hyperventilation for 17.9 minutes.
Ventilation rate: 3.0 times normal. Respiration rate: essentially normal.

1st. Period



2nd. Period

3rd. Period



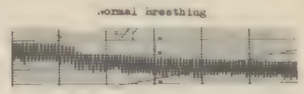
Recovery
1st. Period

2nd. Period

No special subjective symptoms recorded, but following the voluntary hyperventilation the subject continued to breathe somewhat deeper, although more slowly than normal for 1½ min., followed by the development of a rather typical Cheyne-Stokes' rhythm for about 5 min.; respiration then continued shallow with less marked rhythm.
(Downward trend of curve due to leak around neck of subject as he was breathing inside coffin.)

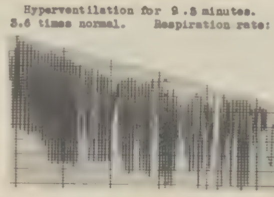
EXPERIMENT D   Oct. 6, 1941

Normal Breathing



Hyperventilation for 9.8 minutes.
Ventilation rate: 3.6 times normal. Respiration rate: essentially normal.

1st. Period



2nd. Period

Towards end of 2nd. hyperventilation period the subject noted numbness of face and fingers; carpopedal spasm was marked. Subject became very weak and experiment was discontinued. It was impossible to obtain tracing of the respiration during recovery.

Chart no. X-13 a

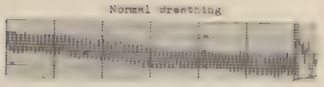
MAYO AERO MEDICAL UNIT

VOLUNTARY HYPERVENTILATION

Subject RWB

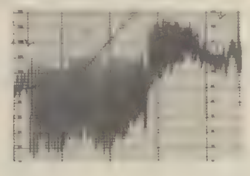
EXPERIMENT A — Oct. 8, 1941

Normal Breathing



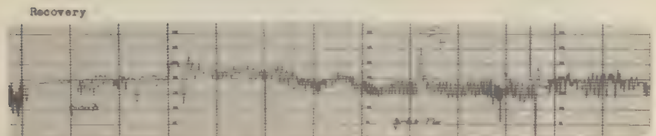
Hyperventilation for 4.0 minutes.
Ventilation rate: 7.1 times normal. Respiration rate: 1.7 to 5.0 times normal.

1st. Period



After 3 minutes of maximal voluntary hyperventilation the subject passed into stage of involuntary hyperventilation of a panting character which continued a minute or more, ending finally in complete apnea. An alveolar air sample was obtained with difficulty towards end of period of involuntary hyperventilation.

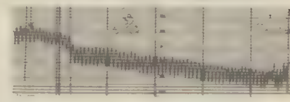
Recovery



The apnea was complete for more than 1 minute followed by shallow and irregular breathing with several short periods of apnea for about 3 minutes. The respiration remained irregular and shallow for the next 8 minutes, gradually becoming more normal. Although tracing for first 13 minutes of recovery was obtained, it was impossible to collect the expired air for the metabolism determination.

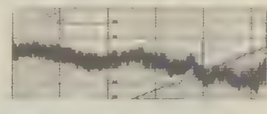
EXPERIMENT B — Oct. 14, 1941

Normal Breathing

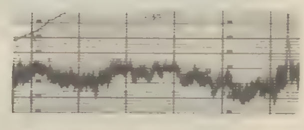


Hyperventilation for 17.7 minutes.
Ventilation rate: 2.6 times normal Respiration rate: 2.3 times normal.

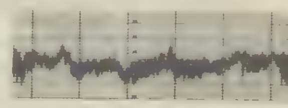
1st. Period



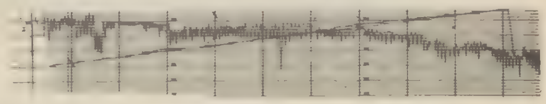
2nd Period



3rd. Period



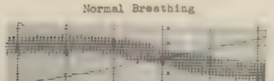
Recovery



No symptoms noted. After hyperventilation ceased the respirations remained irregular for about 2 minutes, followed by one minute of very shallow respiration amounting almost to an apnea. Breathing then tended to become normal.

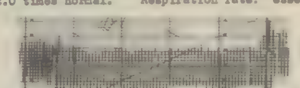
EXPERIMENT C — Sept. 18, 1941

Normal Breathing

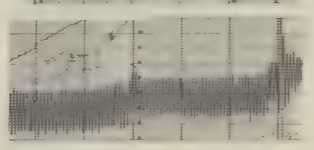


Hyperventilation for 19.0 minutes.
Ventilation rate: 2.0 times normal. Respiration rate: essentially normal.

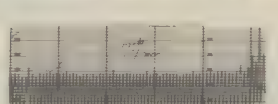
1st. Period



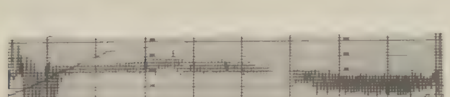
2nd. Period



3rd. Period



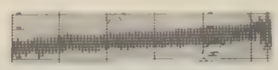
Recovery



Good deep and regular breathing during hyperventilation. Following last alveolar air still automatically continued to breathe deeply for nearly a minute, then shallow breathing for 2 minutes, and after that the respirations were normal.

EXPERIMENT D — Sept. 30, 1941

Normal Breathing

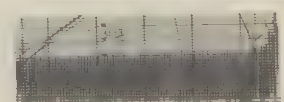


Hyperventilation for 16.3 minutes.
Ventilation rate: 2.8 times normal. Respiration rate: essentially normal.

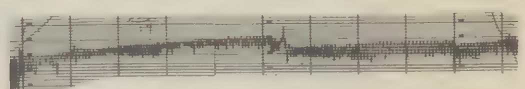
1st. Period

2nd. Period

3rd. Period



Recovery



During the hyperventilation the respirations were maintained deep and regular throughout. In the 15th. minute he became dizzy and on stopping hyperventilation he continued breathing deeply for ½ minute; the respirations were then shallow and irregular for 1 minute, after which breathing tended to become normal.

Chart no. X - 13 b — Dec. 1944

MAYO AERO MEDICAL UNIT

VOLUNTARY HYPERVENTILATION

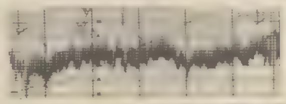
Subject JWW.

EXPERIMENT A — Oct. 13, 1941

Normal Breathing

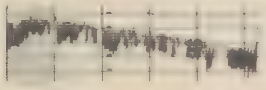
Hyperventilation for 18.0 minutes.
Ventilation rate: 2.1 times normal. Respiration rate: 2.1 times normal.

1st. Period



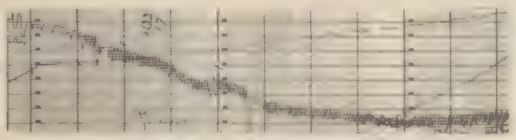
2nd. Period

3rd. Period



During the hyperventilation period the subject breathed rhythmically, especially during the first and third periods.

Recovery



No subjective symptoms were noted. Following the hyperventilation the respirations were irregular and shallow for a short time but were definitely rhythmical.

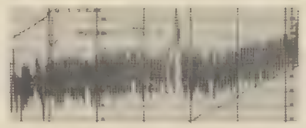
EXPERIMENT B — Sept. 17, 1941

Normal Breathing

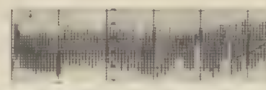
Hyperventilation for 19.3 minutes.
Ventilation rate: 2.3 times normal. Respiration rate: essentially normal.

1st. Period

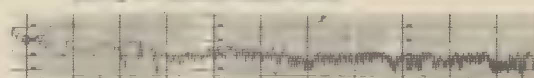
2nd. Period



3rd. Period



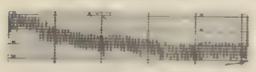
Recovery



No subjective symptoms noted. On cessation of hyperventilation the respirations were very shallow and irregular for 3 to 4 minutes with occasional short periods of apnea. Following this the respirations showed a tendency to be rhythmical.

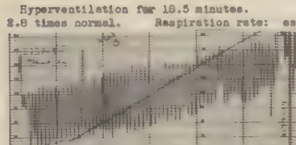
EXPERIMENT C — Sept. 26, 1941

Normal Breathing

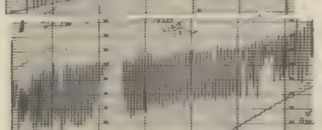


Hyperventilation for 18.5 minutes.
Ventilation rate: 2.8 times normal. Respiration rate: essentially normal.

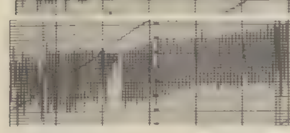
1st. Period



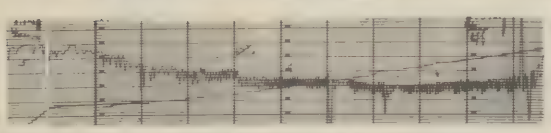
2nd. Period



3rd. Period



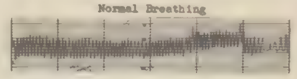
Recovery



No subjective symptoms noted. Following hyperventilation the respirations for 2 minutes were shallow and irregular, with short periods of apnea. The respirations then became rhythmic for several minutes before becoming essentially normal.

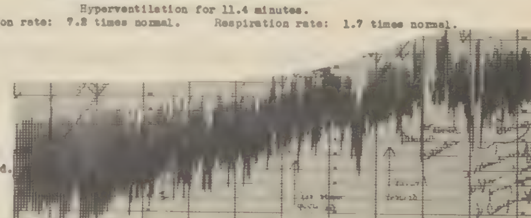
EXPERIMENT D — Oct. 8, 1941

Normal Breathing



Hyperventilation for 11.4 minutes.
Ventilation rate: 7.2 times normal. Respiration rate: 1.7 times normal.

1st., 2nd., 3rd. Periods

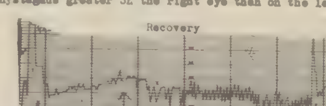


Towards the latter part of the forced breathing the respiration was slightly less deep but more rapid. During last minute of hyperventilation the subject began to have the following symptoms with increasing severity:

(1) numbness of face
(2) spasm of masseter muscles interfering with oral breathing
(3) carpal spasm lasted 4 minutes
(4) twitching arms and forearm
(5) nystagmus greater on the right eye than on the left

Recovery

1st. Period



Following hyperventilation the subject went into practically complete apnea lasting about $2\frac{1}{2}$ minutes. Symptoms so bad that recovery gasometer period was not started until subject started to breathe, and about 1 minute before end of carpal spasm the relaxation of the masseter muscles so that mouth piece could be introduced.

2nd Period

Not until 7 minutes after hyperventilation stopped did the subject begin to feel normal, during which time breathing was irregular and somewhat rhythmic.

3rd. Period

MAYO AERO MEDICAL UNIT

DATA FROM HIGH ALTITUDE LABORATORY

Group VI

NITROGEN ELIMINATION AND EFFECT OF PREOXYGENATION

(1) VI-1 October 1941, J.Piccard modified by W.M.Boothby.
Relative size of the air bubbles and the water volume from which the molecules must come.

(2) VII-1 October 1940, W.M.Boothby, W.R.Lovelace and O.O.Benson.
The rate of nitrogen elimination (plotted on semi-log paper).

(3) VII-1a October 1940, W.M.Boothby, W.R.Lovelace and O.O.Benson.
The rate of nitrogen elimination (plotted on log-log paper).

(4) VII-2 November 1942, F.J.Robinson, H.C.Shands and E.Larson.
Comparison of (1) Gaseous nitrogen eliminated from the lungs (accumulated) while breathing oxygen and (2) Venous (antecubital) blood nitrogen content.

(5) VII-3 September 1942, F.J.Robinson.
Comparison of nitrogen eliminated by heavy and light subjects
(a) body weight
(b) transposed proportionally for weight of 70 kgs.

(6) VII-8b August 1944, J.B.Bateman.
Effect of preoxygenation on degree of immunity from symptoms of bends.

(7) VII-8c August 1944, J.B.Bateman.
Effects of prolonged inhalation of gas mixture compared with effects of preoxygenation.

(8) VII-8e August 1944, J.B.Bateman.
Comparison nitrogen elimination curves from data of Behnke and Willmon with data of Boothby, Lovelace and Benson. (Semi-log paper plotting fraction of normal dissolved nitrogen remaining after oxygen inhalation).

(9) VII-8d September 1944, J.B.Bateman.
Principle of equilibration method in study of decompression sickness

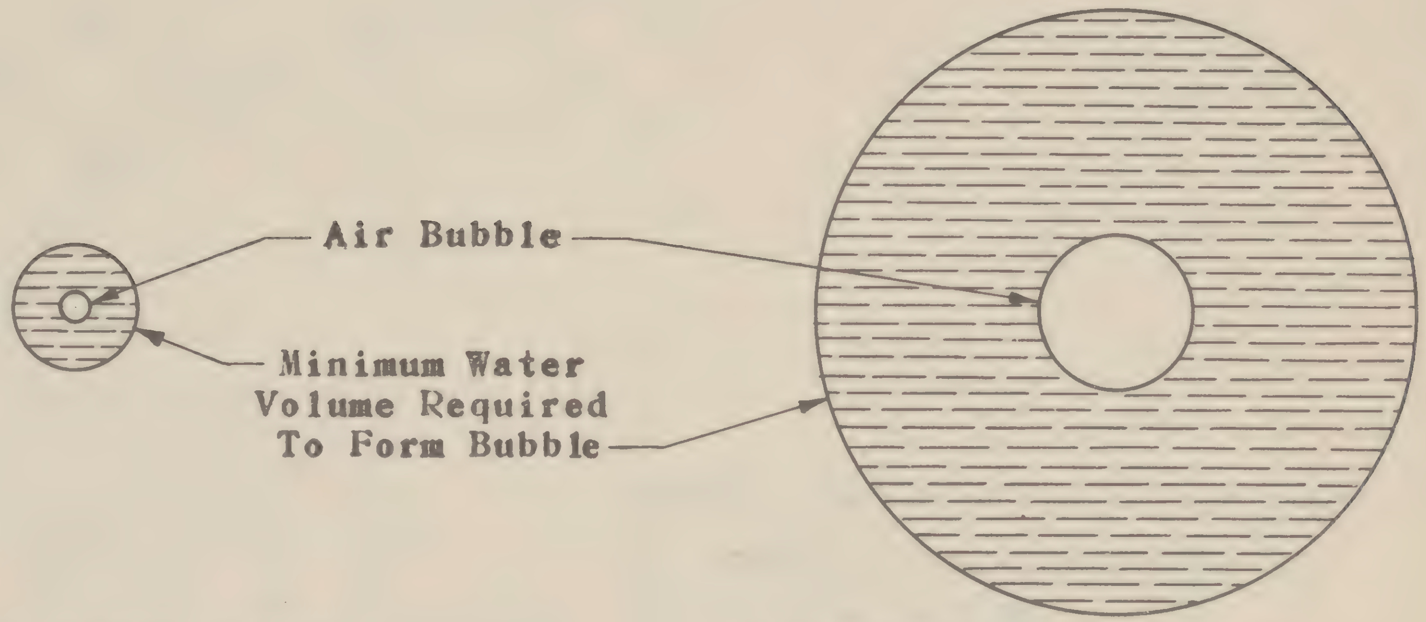
(10) VII-8g August 1944, J.B.Bateman.
Scores obtained after "equilibration" with gas mixtures.

(11) VII-8f-2 September 1944, J.B.Bateman.
Course of elimination of symptom-producing nitrogen.

RELATIVE SIZE OF THE AIR BUBBLES
AND THE WATER
VOLUME FROM WHICH THE MOLECULES MUST COME

CASE I
Pressure Reduced from
5 Atmospheres to 1 Atmosphere

CASE II
Pressure Reduced from
1 Atmosphere to 1/5 Atmosphere



Case I

AIR BUBBLE AND WATER VOLUME	
Radius	0.365μ
Volume	0.205μ^3
No. Molecules Air	27.6 x 10^6
Minimum amount of water containing these air molecules	
Radius	1.43μ
Volume	12.28μ^3

Case II

AIR BUBBLE AND WATER VOLUME	
Radius	1.82μ
Volume	25.7μ^3
No. Molecules Air	690 x 10^6
Minimum amount of water containing these air molecules	
Radius	7.15μ
Volume	1538 μ^3

VI-1 1941

1 Micron (μ) = 0.001 Millimeter

Boothby
Modified from Prof. Piccard

MAYO AERO MEDICAL UNIT

THE RATE OF NITROGEN ELIMINATION

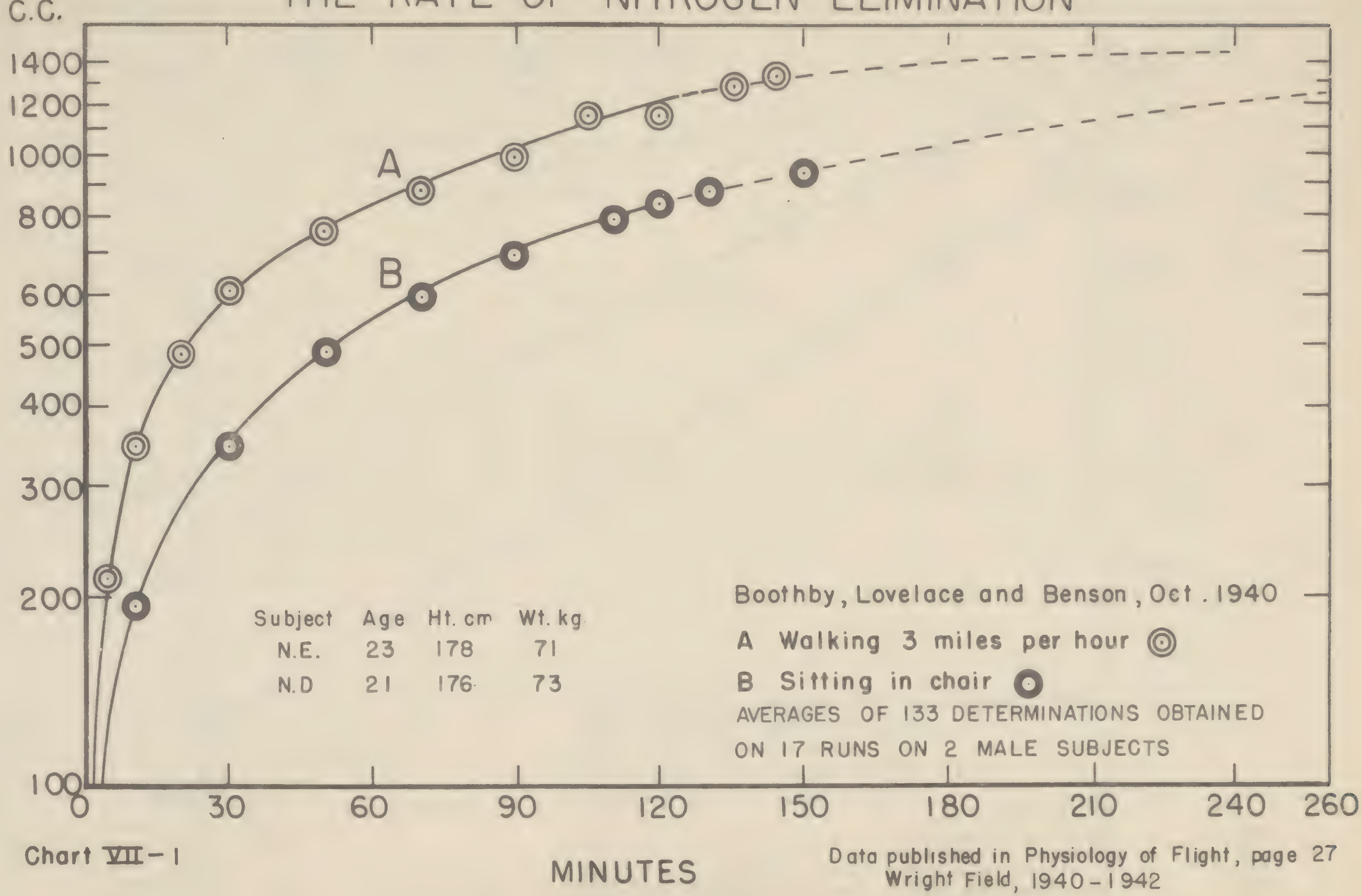


Chart VII-1

Data published in Physiology of Flight, page 27
Wright Field, 1940-1942

MAYO AERO MEDICAL UNIT

THE RATE OF NITROGEN ELIMINATION

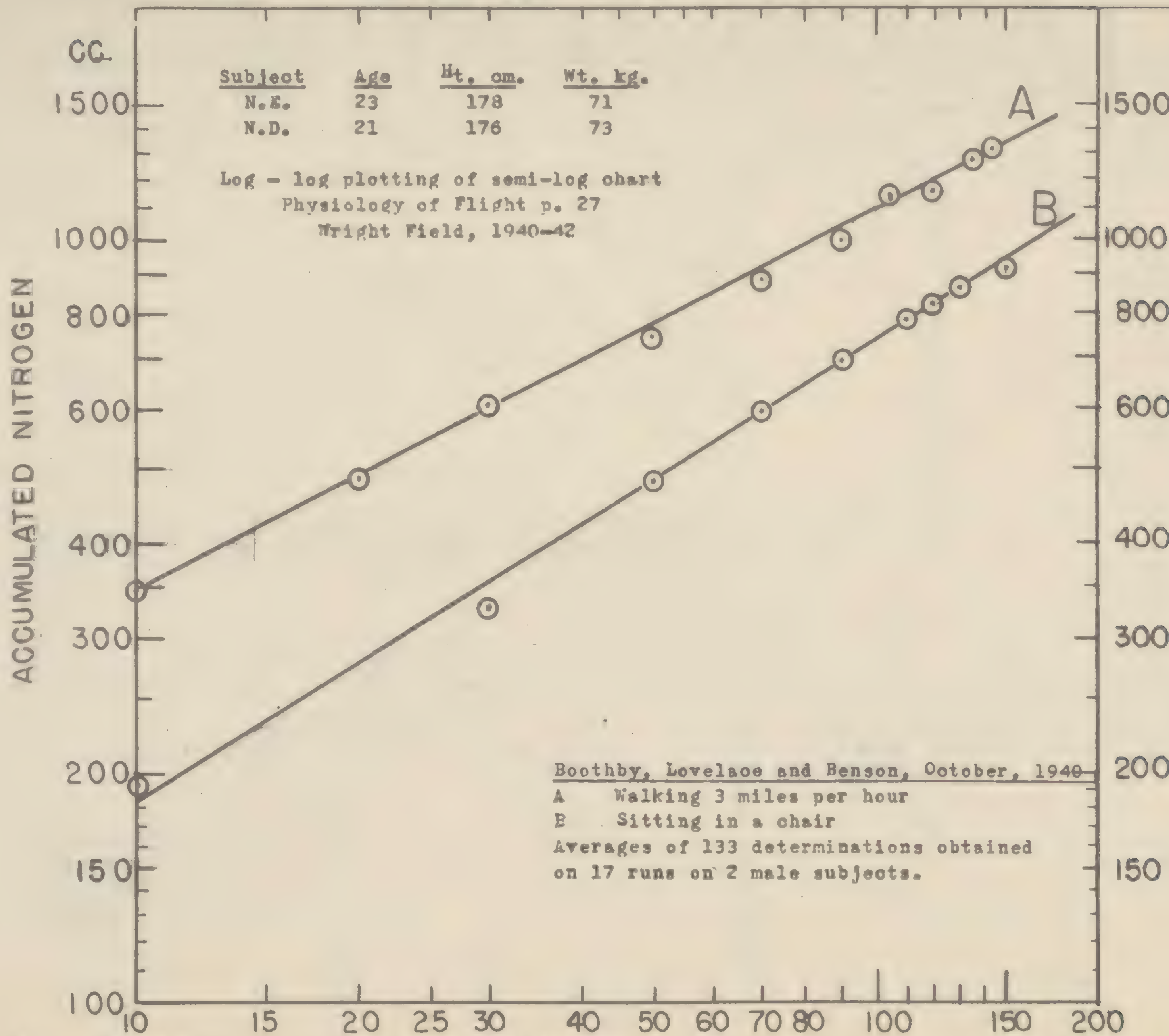
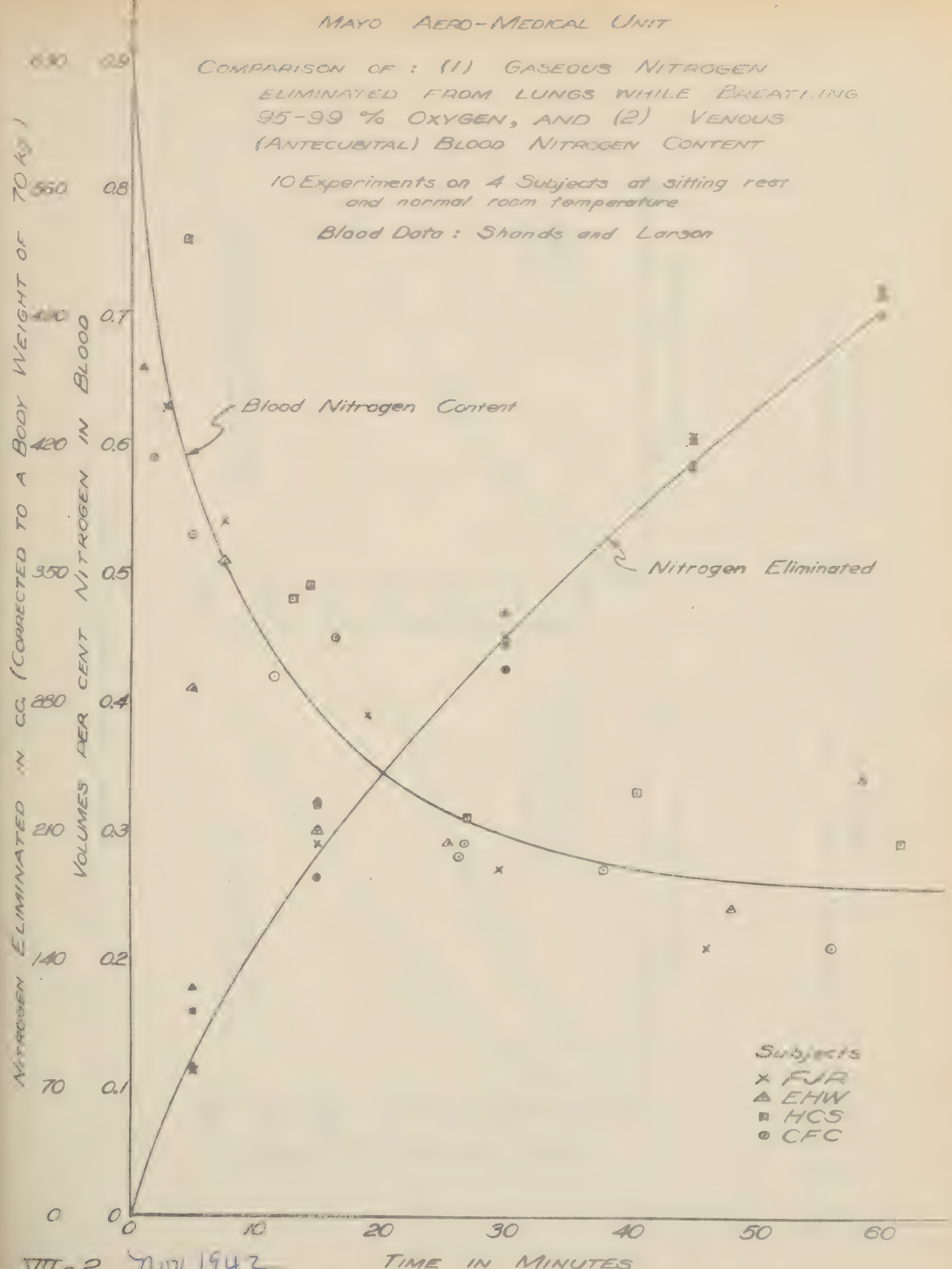


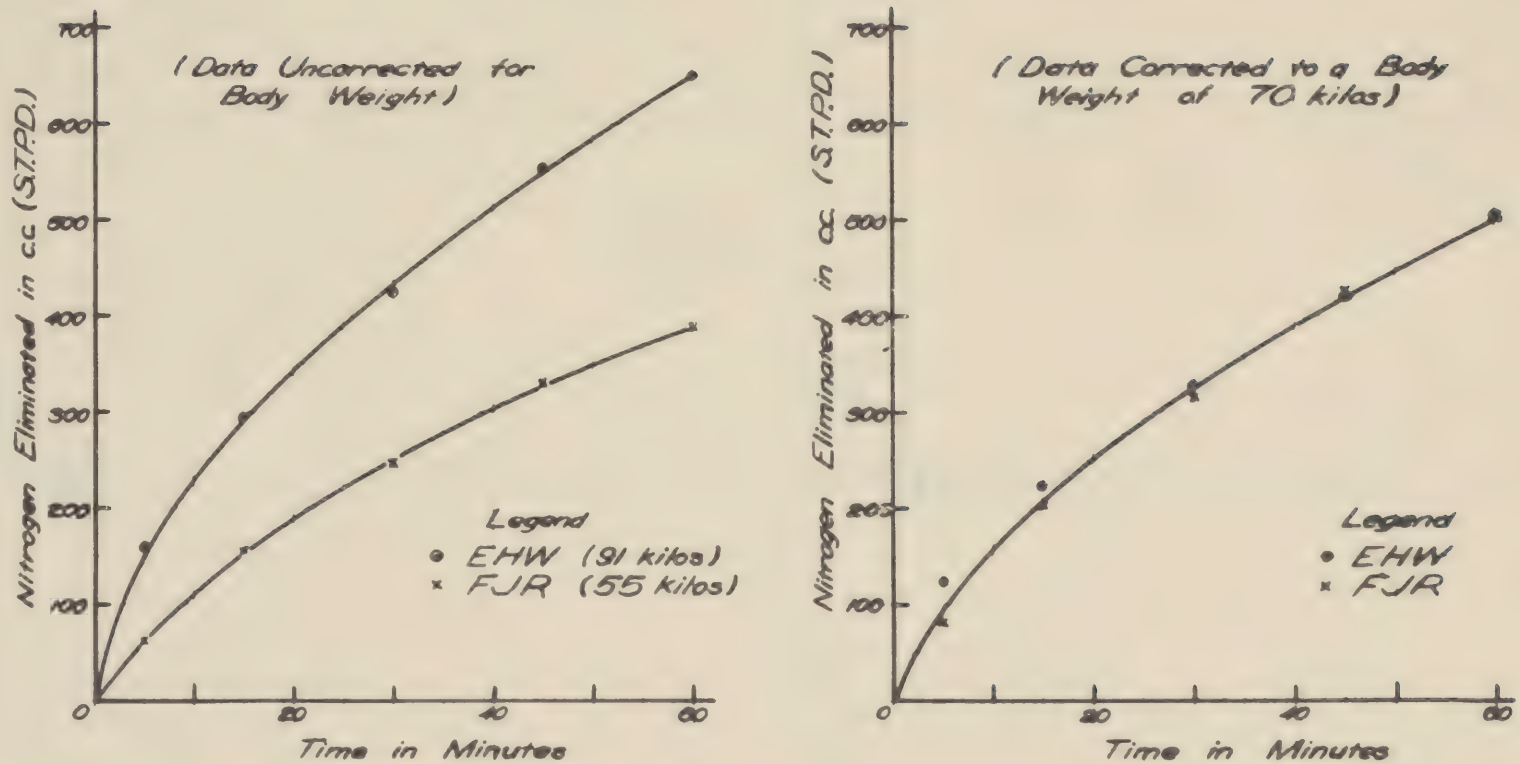
Chart VII-1a

W.M.Boothby May 1946



VIII-2 Nov 1942

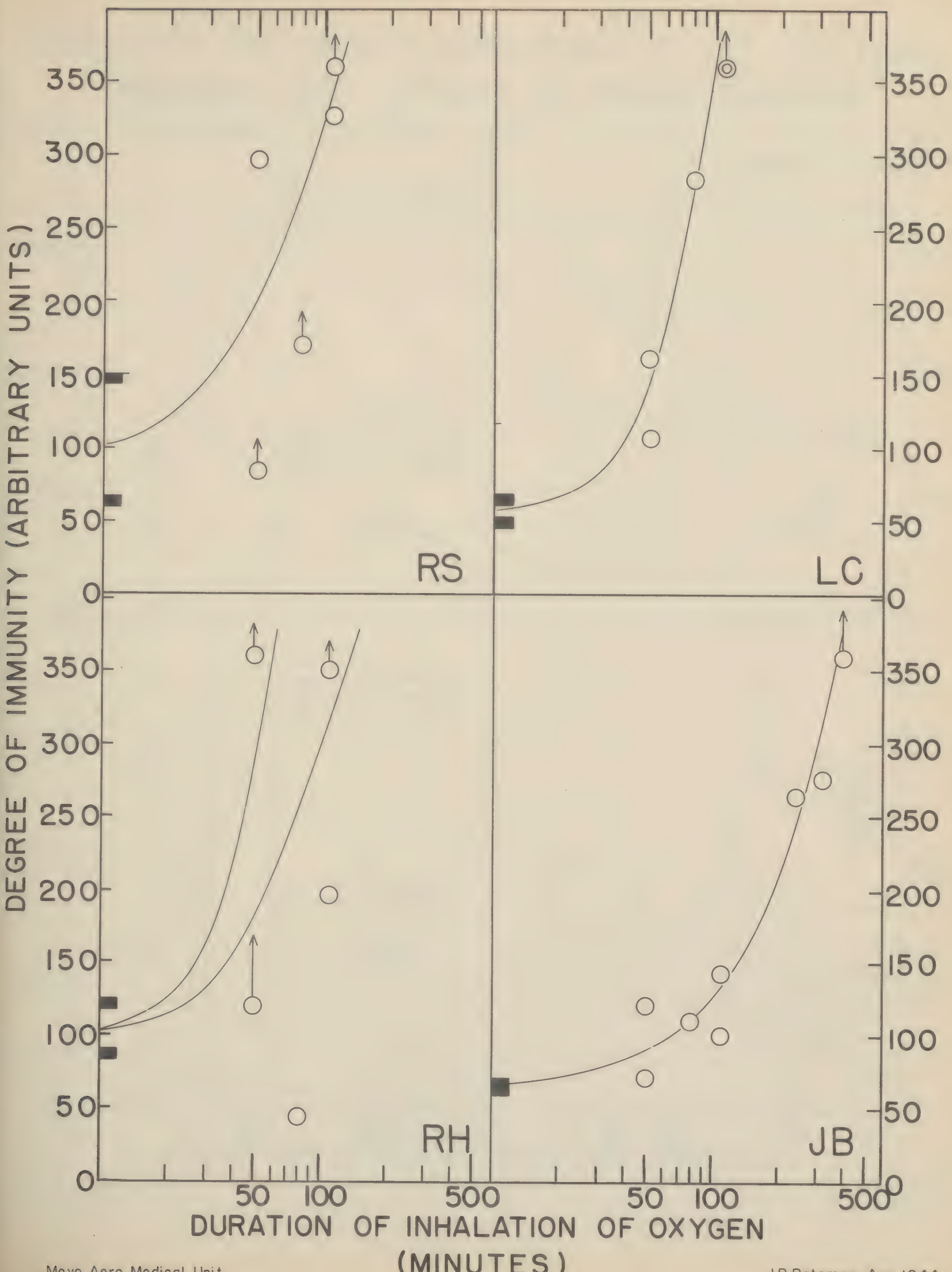
Robinson, H Shands & E Larson



VIII-3 COMPARISON OF NITROGEN ELIMINATED BY HEAVY AND LIGHT SUBJECTS

F. J. Robinson Sept 1942

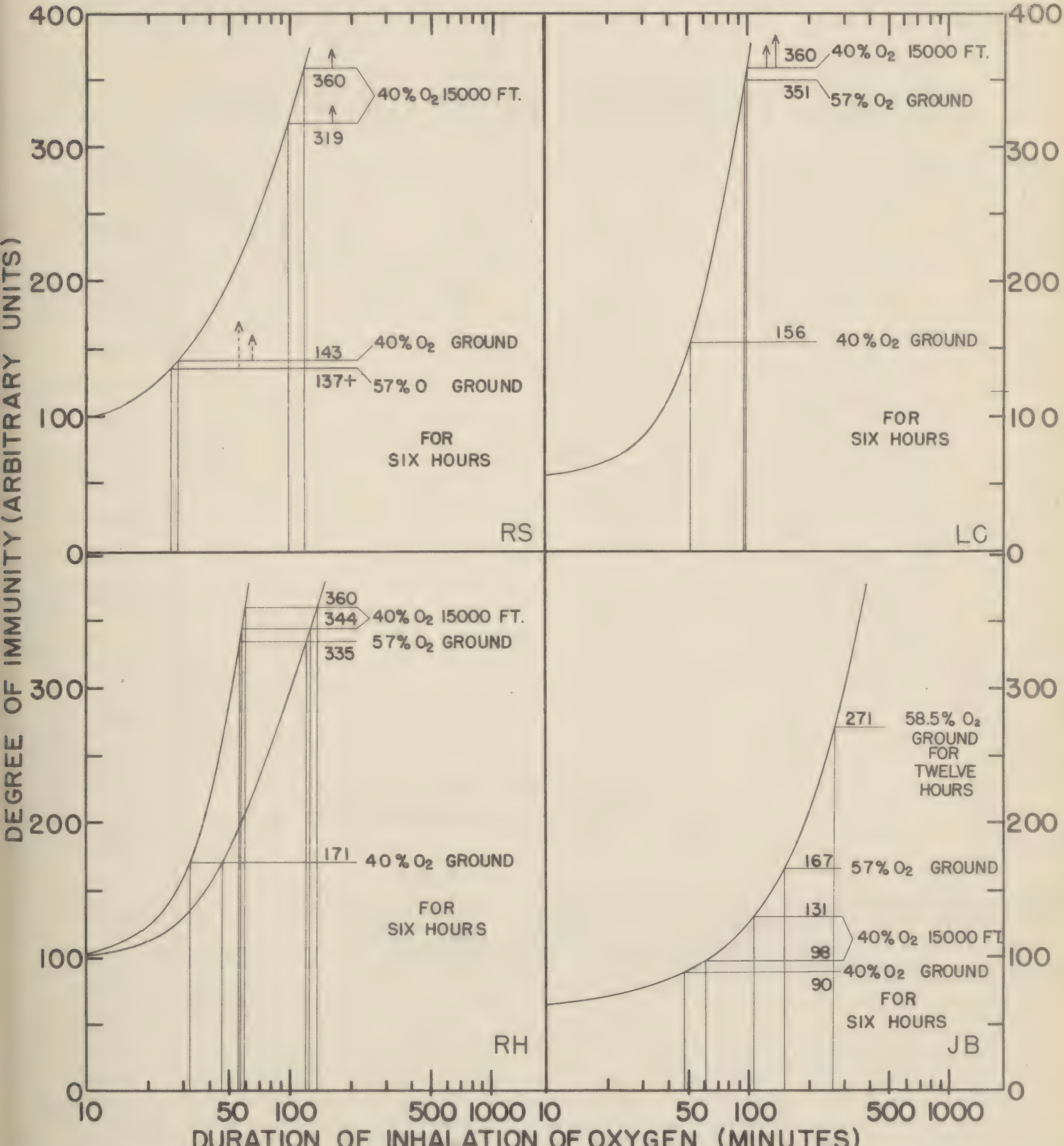
EFFECTS OF PREOXYGENATION



Mayo Aero Medical Unit
Chart No VII–8 b

J.B. Bateman Aug. 1944

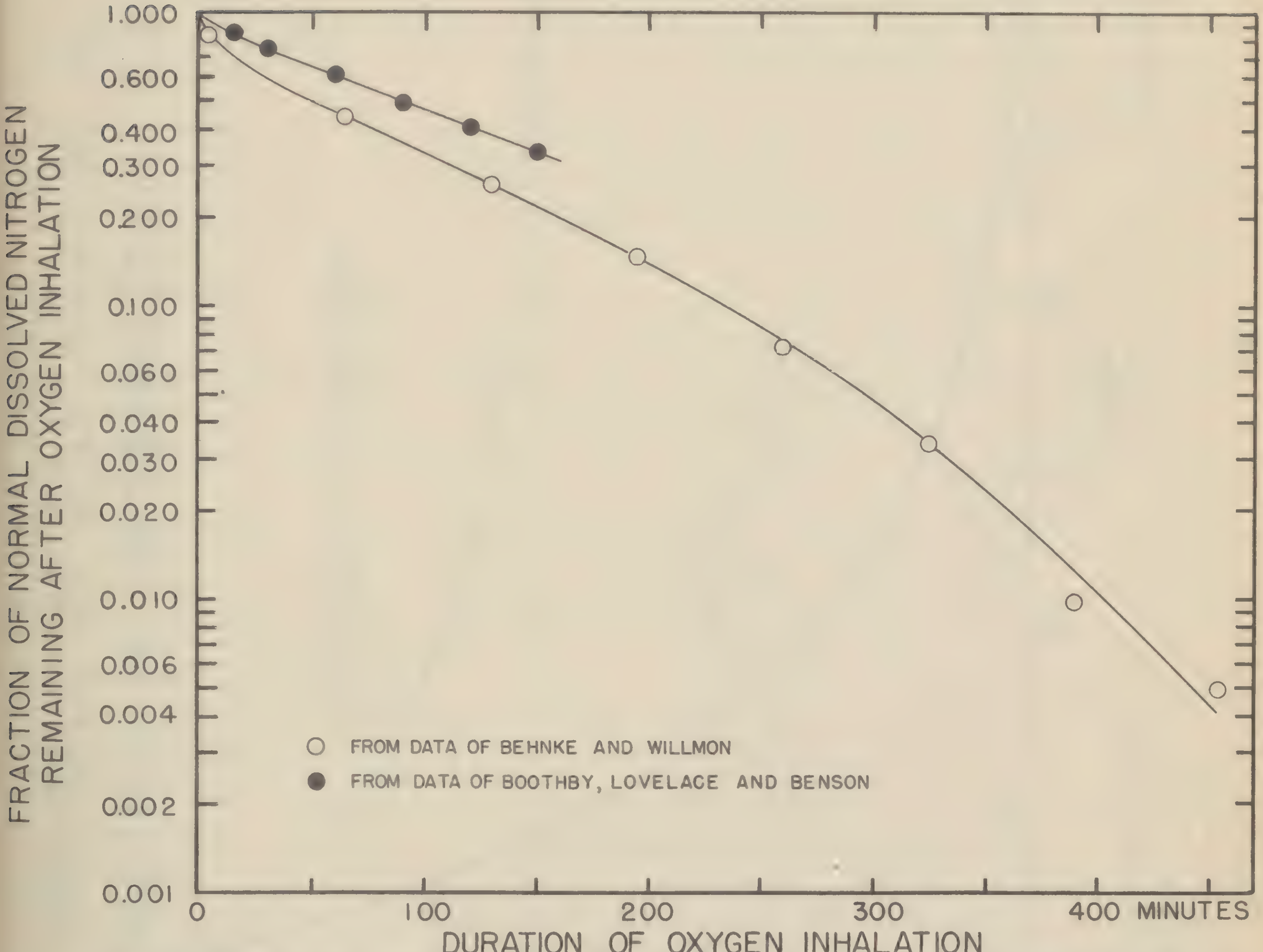
EFFECTS OF PROLONGED INHALATION OF GAS MIXTURES COMPARED WITH EFFECTS OF PREOXYGENATION



Mayo Aero Medical Unit
Chart No. VII-8c

J.B. Bateman
Aug. 1944

NITROGEN ELIMINATION CURVES

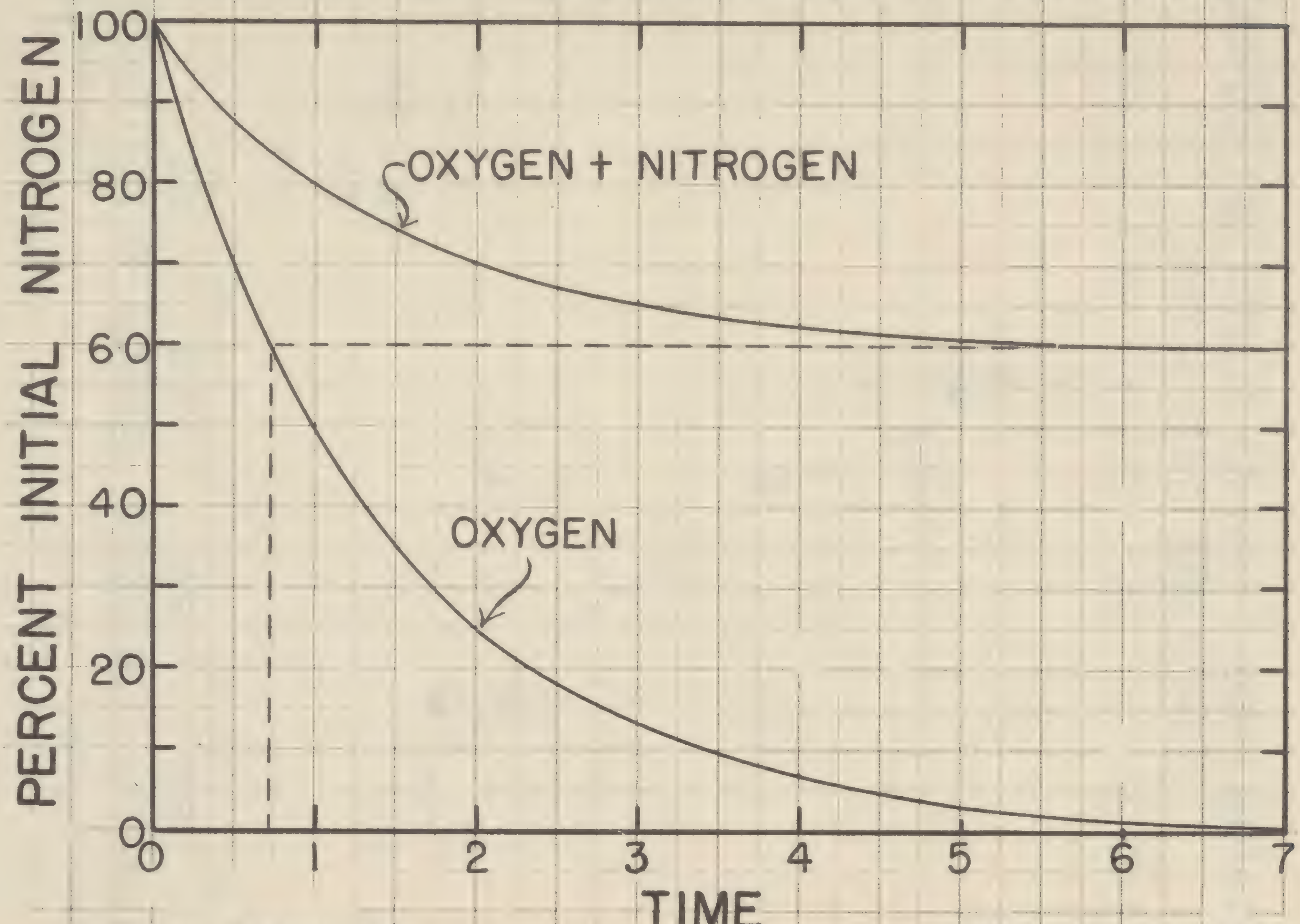


Mayo Aero Medical Unit
Chart No. VII - 8 e

J.B.Bateman Aug. 1944

8

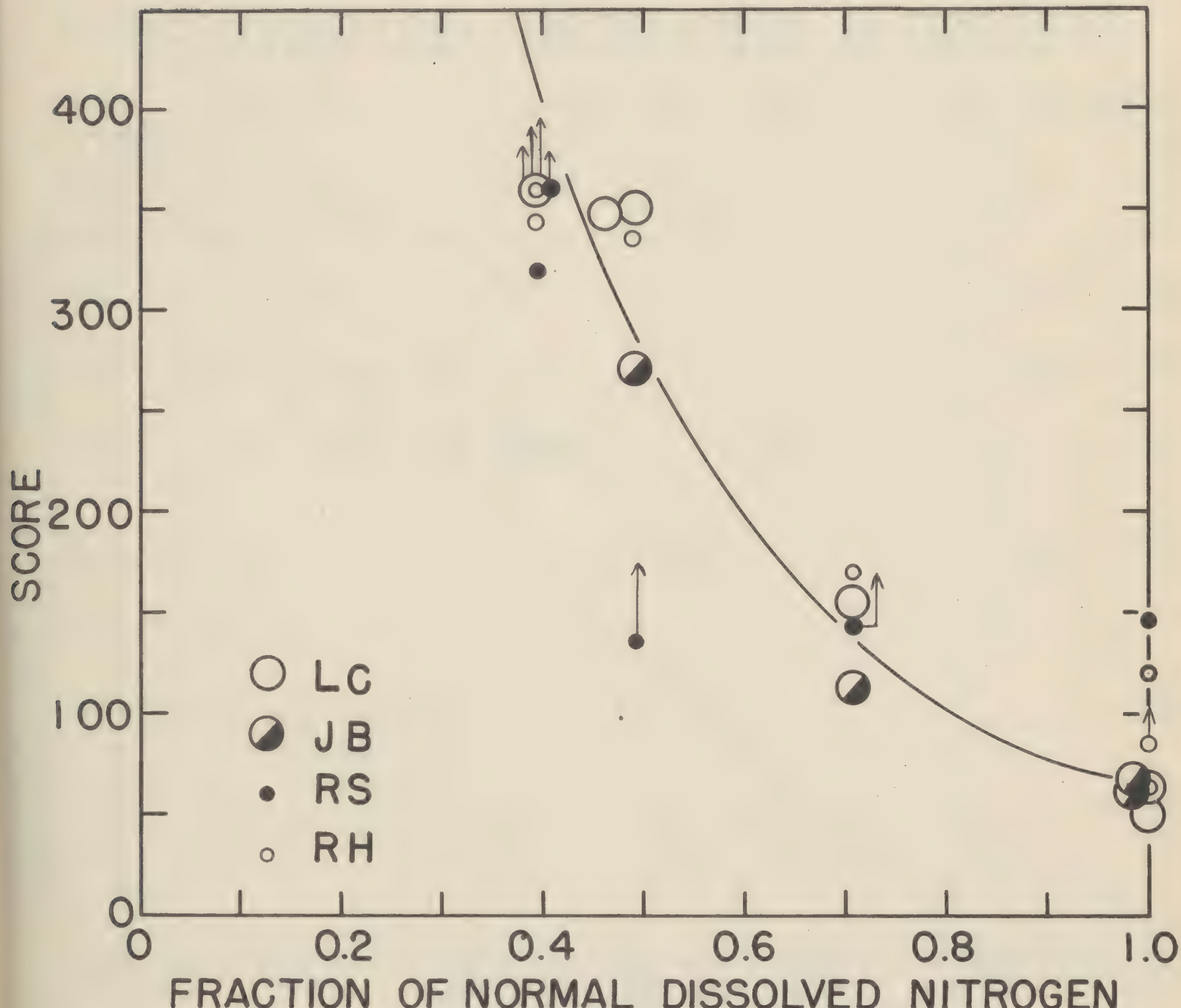
PRINCIPLE OF EQUILIBRATION METHOD IN STUDY OF DECOMPRESSION SICKNESS



Mayo Aero Medical Unit
Chart VII 8 d

J.B.Bateman Sept. 1944

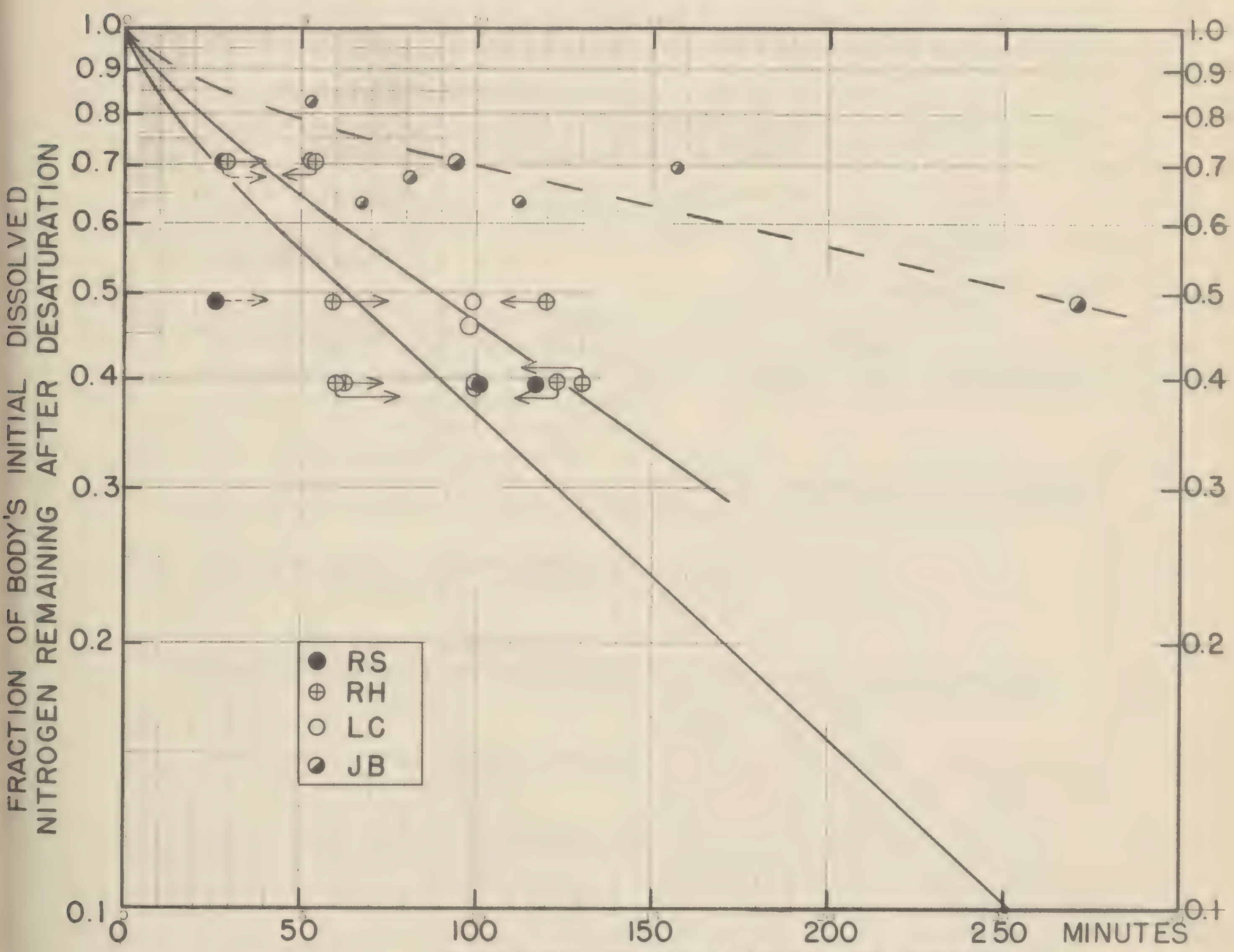
SCORES OBTAINED AFTER "EQUILIBRATION" WITH GAS MIXTURES



Mayo Aero Medical Unit
Chart VII — 8 g

J.B. Bateman Aug. 1944

COURSE OF ELIMINATION OF SYMPTOM-PRODUCING NITROGEN



MAYO AERO MEDICAL UNIT
Chart VII - 8f-2

J.B. Bateman Sept. 1944

MAYO AERO MEDICAL UNIT

DATA FROM HIGH ALTITUDE LABORATORY

Group VII

EFFUSION TIME OF GASES AND THEIR FLOW CHARACTERISTICS THROUGH SINGLE ORIFICES AND THROUGH SPONGE RUBBER DISKS.

(1) XX-1 January 1939, W.M.Boothby and H.O.Brown
Effusion time of gases through 0.005 inch orifice at various pressures.

(2) V-3 February 1945, W.M.Boothby
Repetition of experiments of Boothby, Lovelace and Benson in 1940 on flow characteristics of sponge rubber disks.

(3) V-4 February 1945, H.F.Helmholz Jr.
Flow characteristics of 1/2" and 5/16" orifice and 2 standard sponge rubber disks.

(4) V-5 February 1945, H.F.Helmholz and W.M.Boothby
Comparison of resistance characteristics at ground level and at 28,000 ft. to increase gas flows (1) 1/4" orifice (2) Two dry sponge rubber disks (3) Two wet sponge rubber disks.

(5) V-6 May 1945, W.M.Boothby
Flow characteristics of air, argon and helium using adjustable low resistance flow meter with varying number of sponge rubber disks.

(6) V-7 May 1945 W.M.Boothby
Same as (5) with comparison of ground and 30,000 ft.

(7) V-8 March 1946, W.M.Boothby
Flow characteristics of Oxygen using adjustable sponge rubber resistor with 1 to 6 disks.

(8) V-9 March 1946, W.M.Boothby
Same as (7) for Argon.

(9) V-10 March 1946 W.M.Boothby
Same as (7) for Helium

Graham's Law

Effusion Time of Gases through 0.005 inch Orifice at Various Pressures

MAYO AERO MEDICAL UNIT

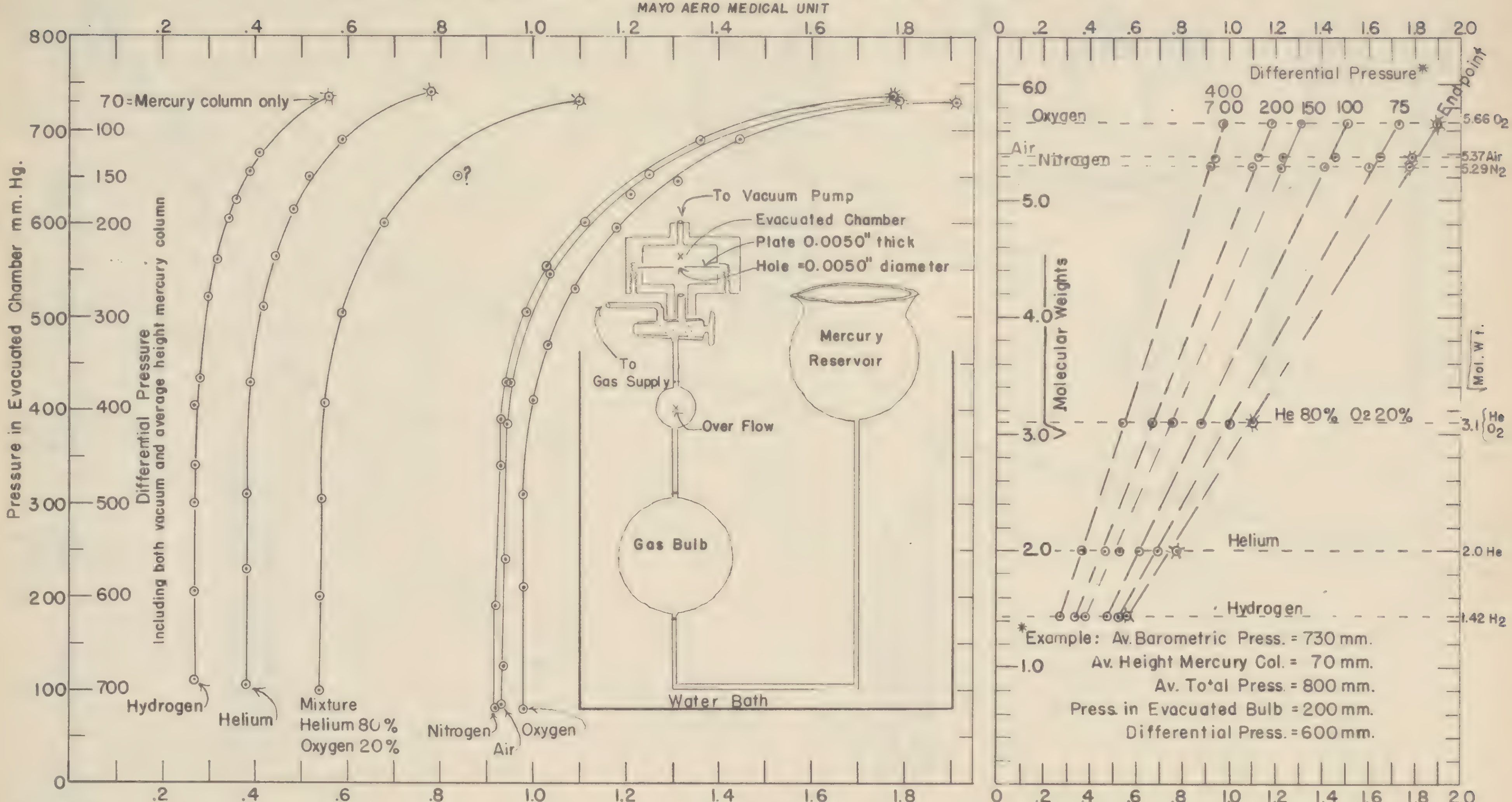


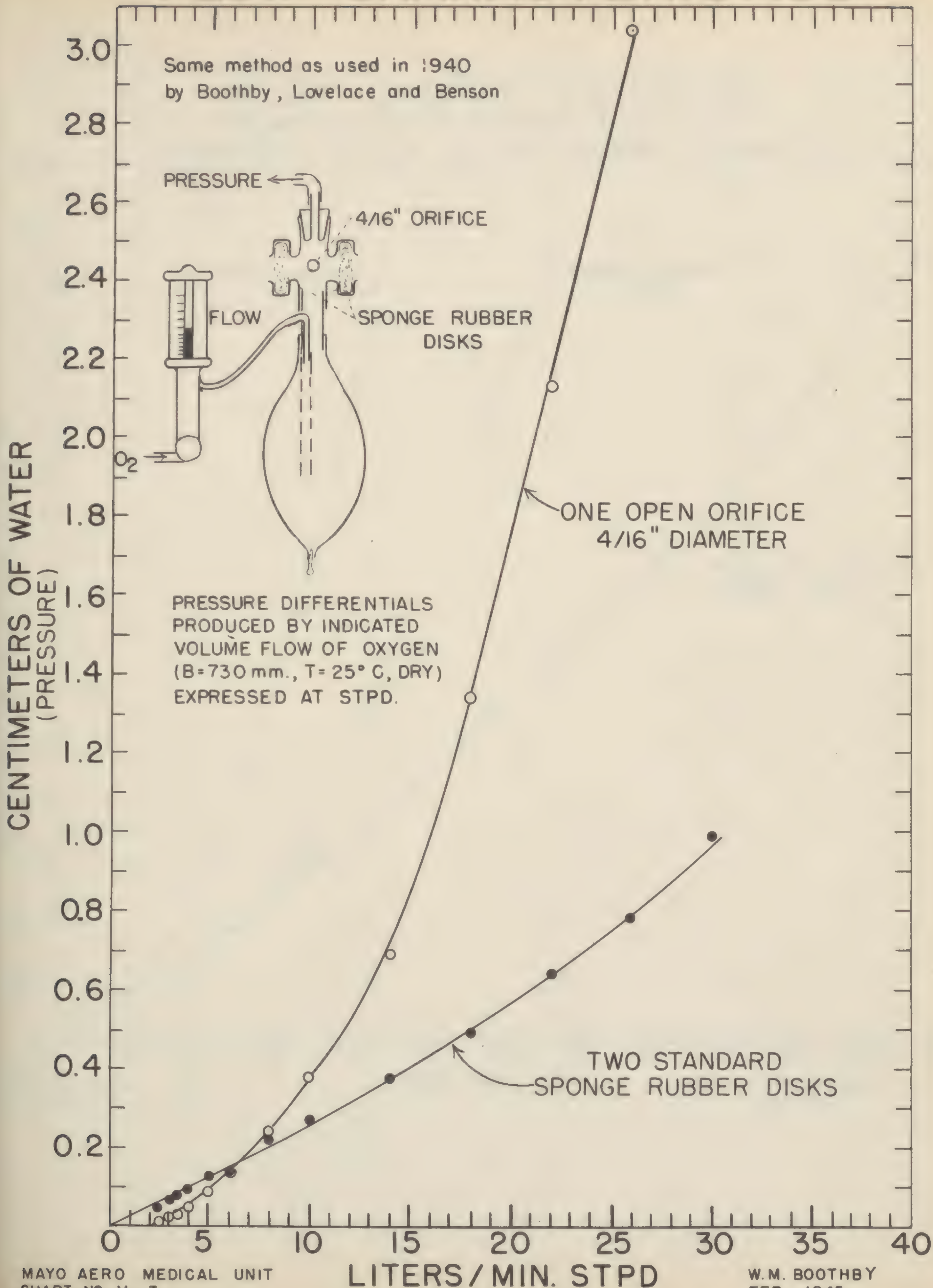
Chart XX – 1

Time in ~~Seconds~~ min.

Required for Gas to Effuse out of Bulb under Several Constant Differential Pressures

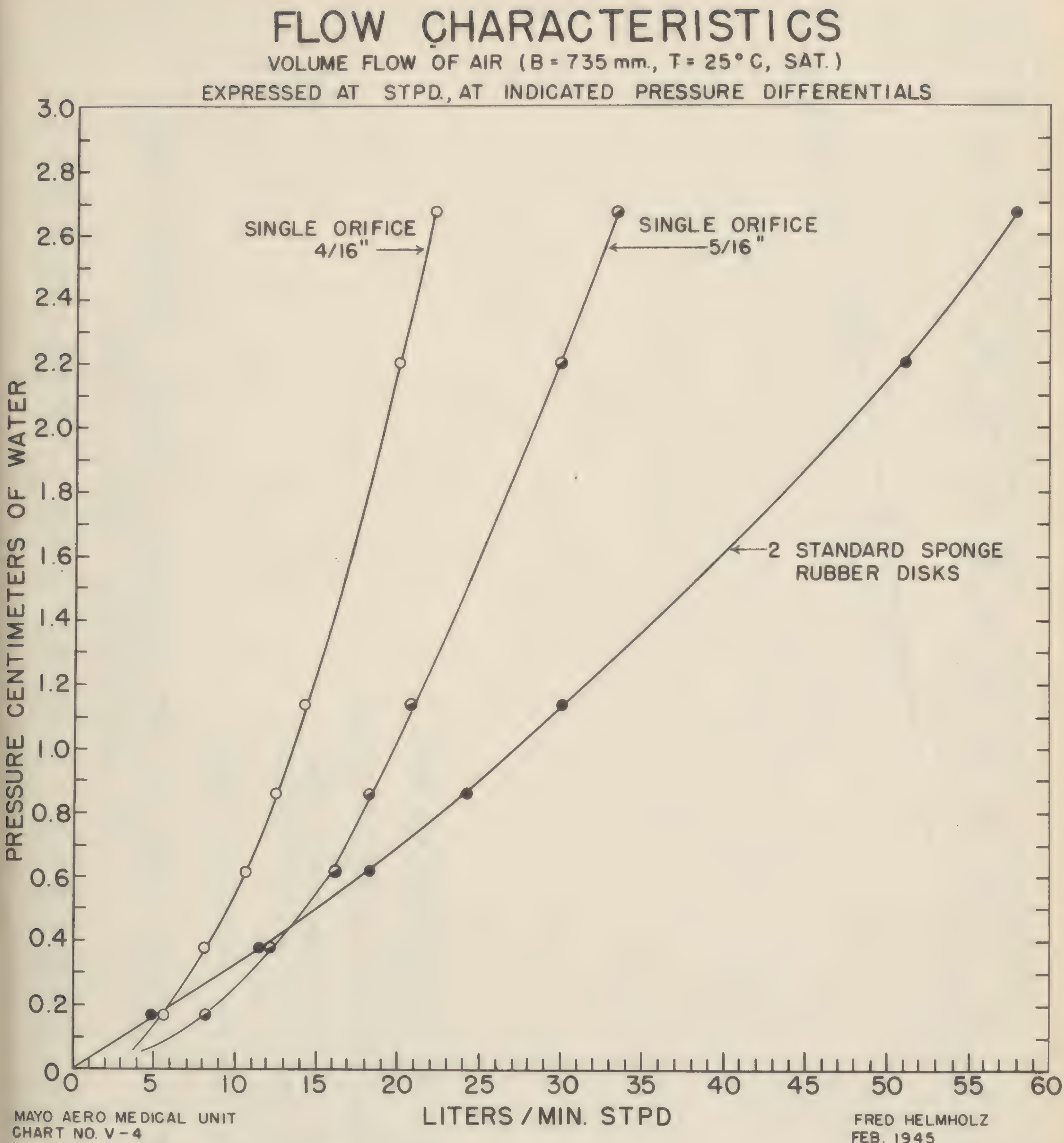
W. M. Boothby and H. O. Brown Jan. 1939

FLOW CHARACTERISTICS



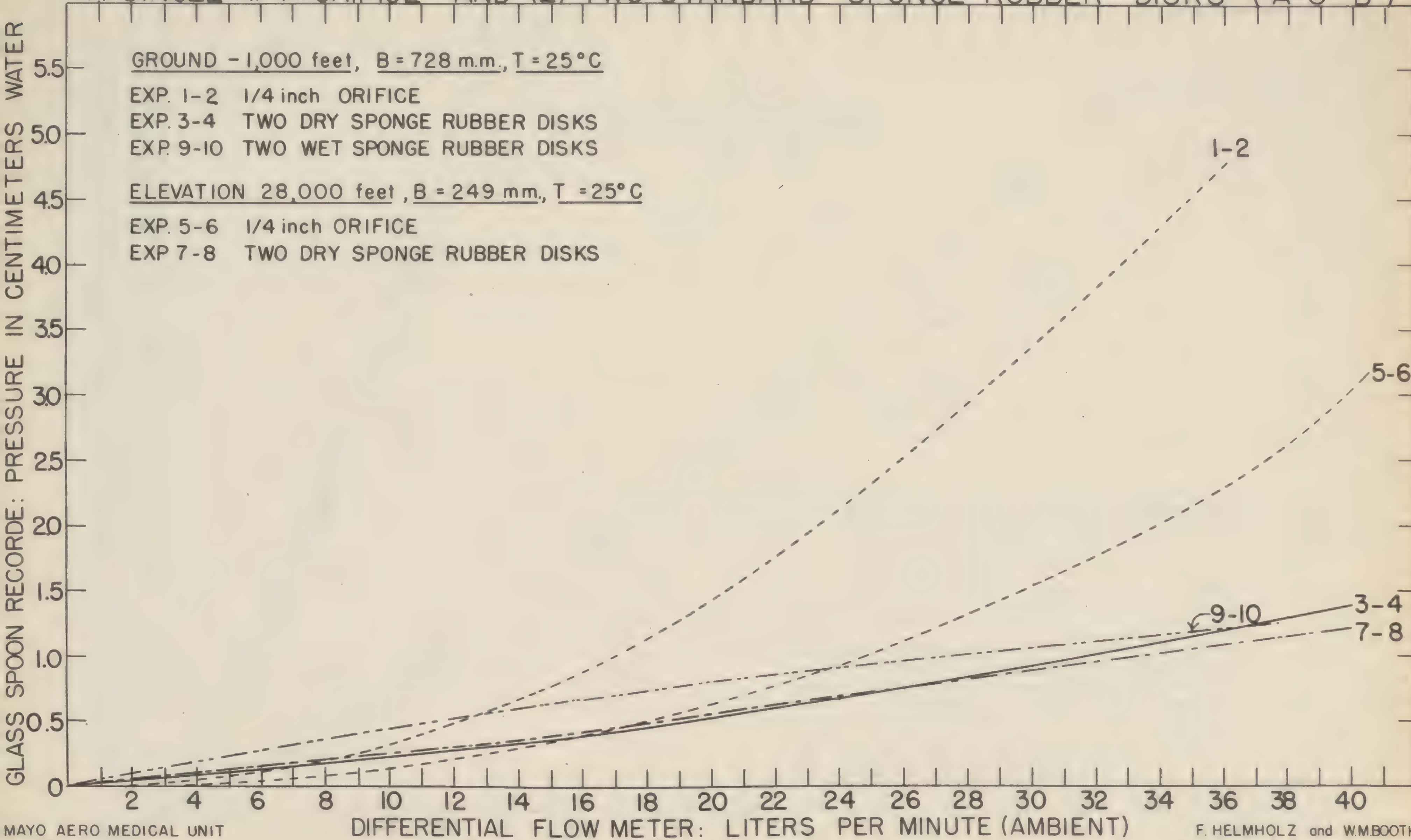
MAYO AERO MEDICAL UNIT
CHART NO. V-3

W.M. BOOTHBY
FEB. 1945


FLOW CHARACTERISTICS
VOLUME FLOW OF AIR (B = 735 mm., T = 25° C, SAT.)
EXPRESSED AT STPD., AT INDICATED PRESSURE DIFFERENTIALS
PRESSURE CENTIMETERS OF WATER
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
SINGLE ORIFICE 4/16"
SINGLE ORIFICE 5/16"
2 STANDARD SPONGE RUBBER DISKS
0
5
10
15
20
25
30
35
40
45
50
55
60
LITERS / MIN. STPD
MAYO AERO MEDICAL UNIT
CHART NO. V-4
FRED HELMHOLZ
FEB. 1945

COMPARISON OF RESISTANCE CHARACTERISTICS TO INCREASING GAS FLOWS

(1) SINGLE 1/4" ORIFICE AND (2) TWO STANDARD SPONGE RUBBER DISKS (A-8-B)



MAYO AERO MEDICAL UNIT
CHART NO. V - 5

F. HELMHOLZ and W.M.BOOTHBY
FEB. 1945

MAYO AERO MEDICAL UNIT

ADJUSTABLE LOW RESISTANCE FLOW METER

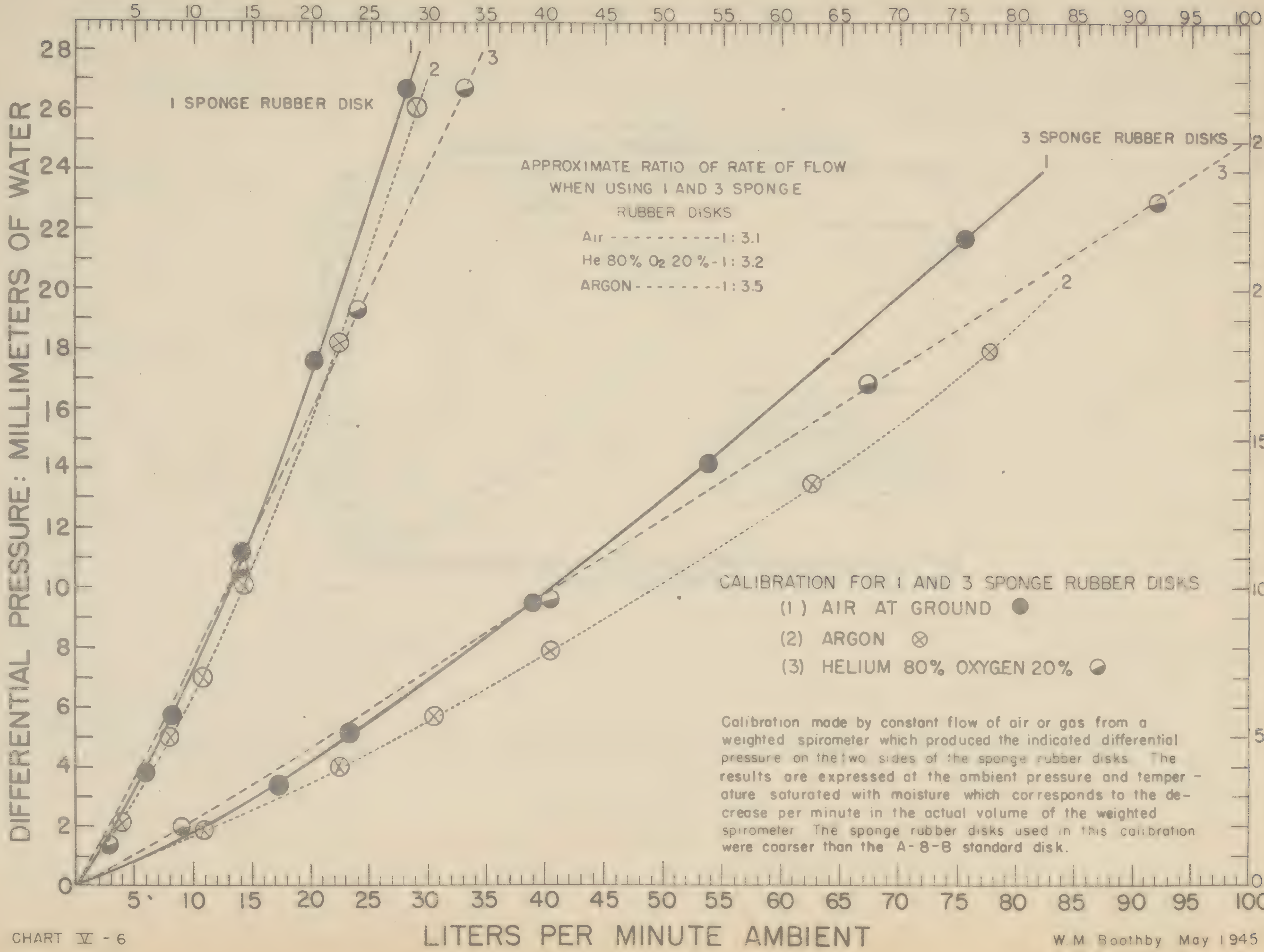


CHART V - 6

W. M. Boothby May 1945

MAYO AERO MEDICAL UNIT

ADJUSTABLE LOW RESISTANCE FLOW METER

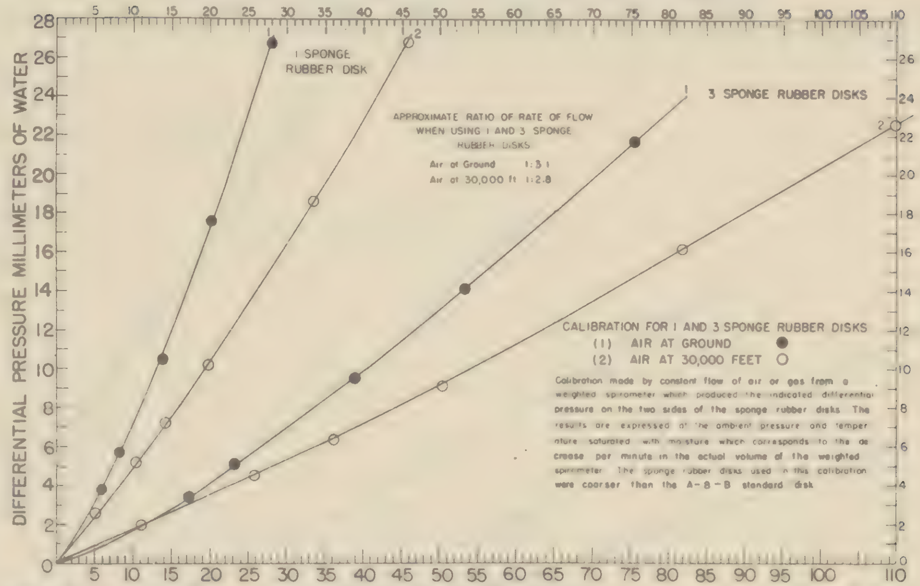
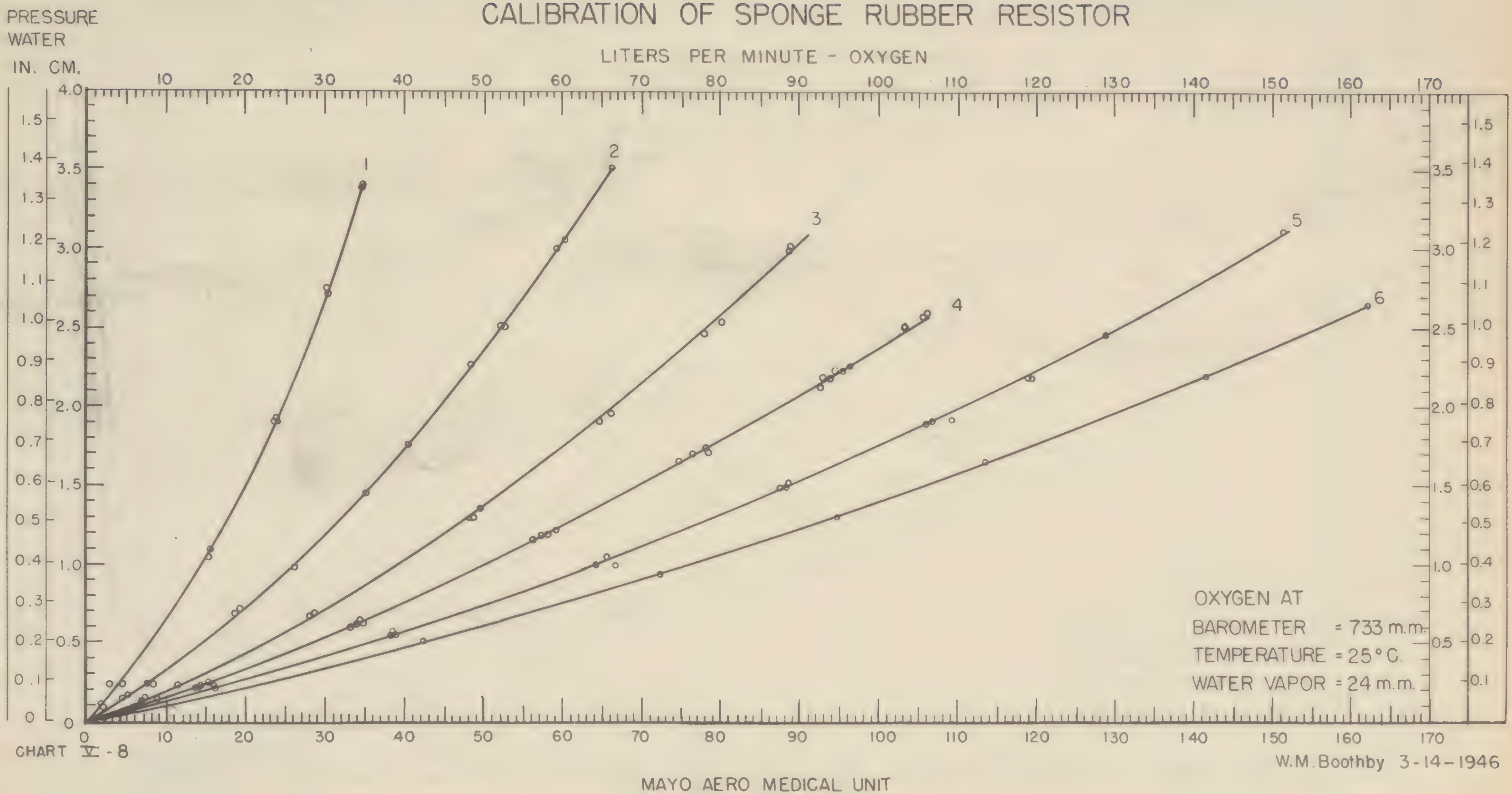


Chart V-7

W M Boothby May 1945

CALIBRATION OF SPONGE RUBBER RESISTOR



CALIBRATION OF SPONGE RUBBER RESISTOR

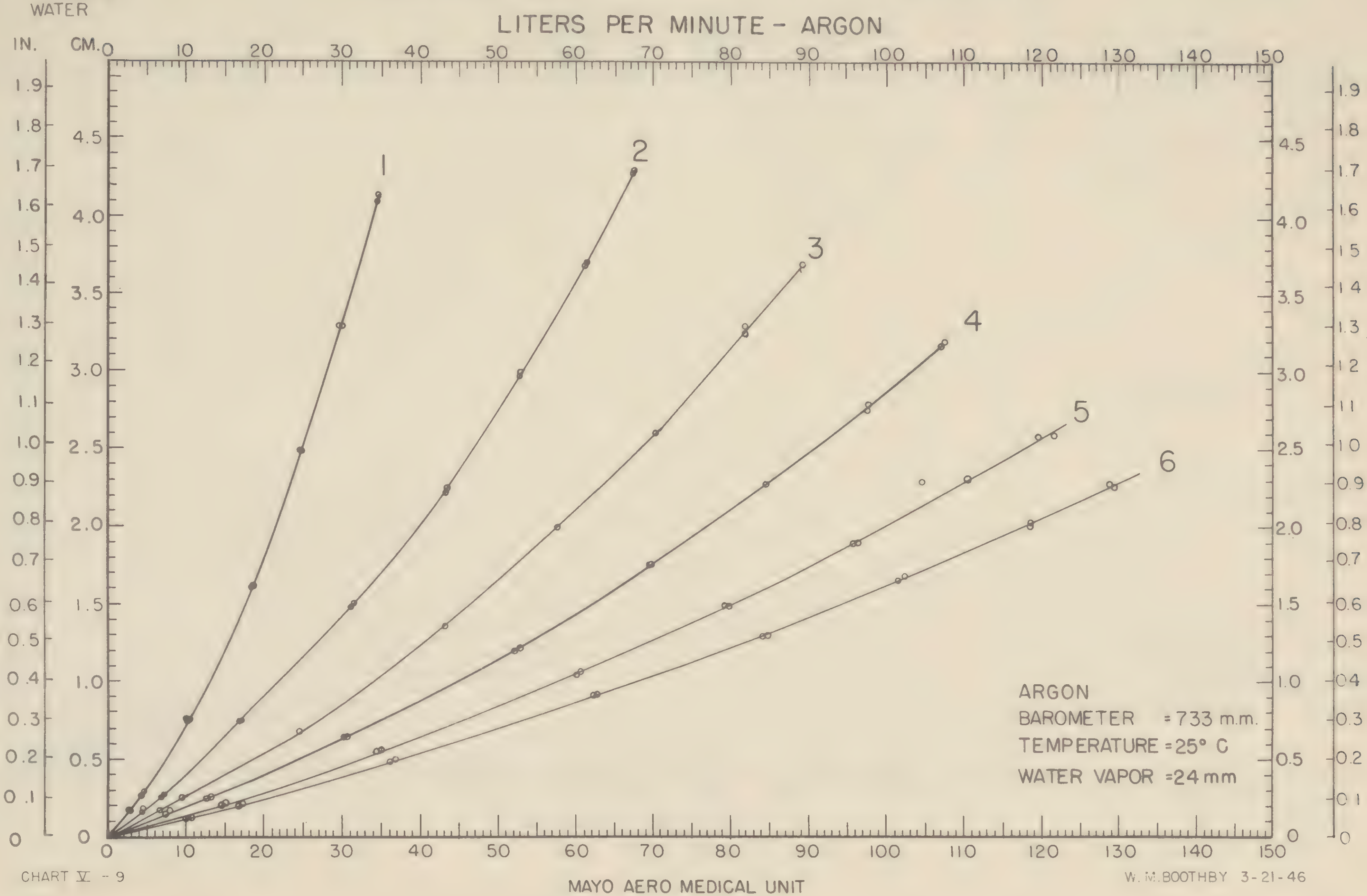


CHART V - 9

W. M. BOOTHBY 3-21-46

CALIBRATION OF SPONGE RUBBER RESISTOR

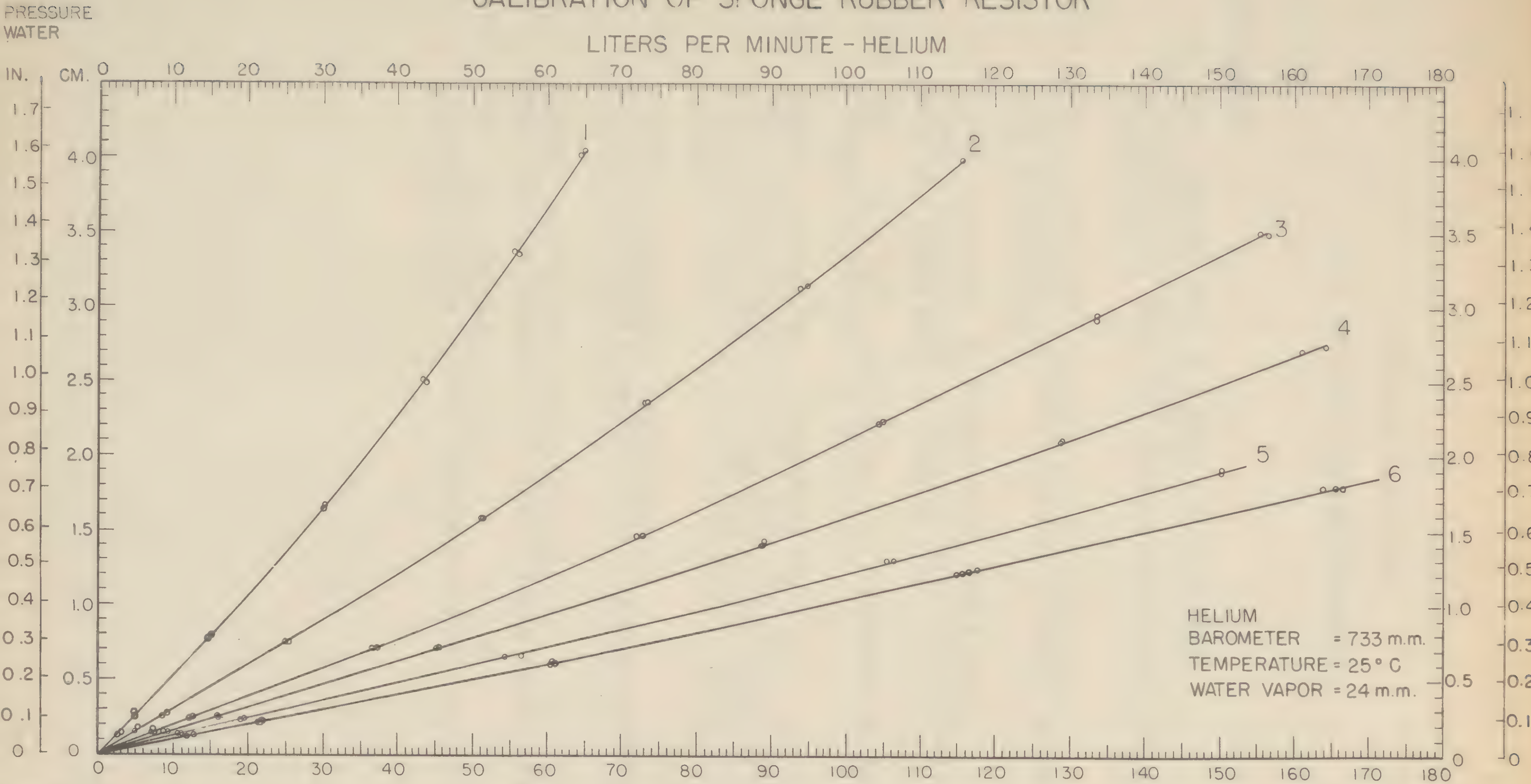


CHART V - 10

W. M. BOOTHBY 3-21-46

MAYO AERO MEDICAL UNIT

DATA FROM HIGH ALTITUDE LABORATORY

Group VIII

MISCELLANEOUS

(1) XI-6 November 1939, H.O Brown and W.M.Boothby
Respiratory curves produced by
(a) Decreas ng oxygen concentration and (b) increasing carbon dioxide concentration.

(2) XIV-1 January 1940, W.M.Boothby and O.O.Benson.Jr.
Oxygen consumption and ventilation rate per minute at various altitudes while breathing oxygen.

(3) III-5A June 1942, Lt. M.Mason Guest, Wright Field.
Oxygen dissociation curves for human blood. Curves based on data of Major Dill Wright Field Aero Medical Unit.

(4) IX-7 August 1944, H.F.Helmholz Jr., J.B.Bateman and W.M.Boothby.
Increased circulation rate with anoxia.

(5) III-12a November 1944 H. F.Helmholz Jr.
Oxygen carrying capacity of the blood. The effect of altitude with and without the addition of oxygen. Arterial hemoglobin saturation calculated from experimental alveolar air data by means of Henderson's nomogram.

(6) III-12b November 1944, H.F.Helmholz Jr.
Effect of decreasing barometric pressure on oxygen transport by the blood increase in circulation.

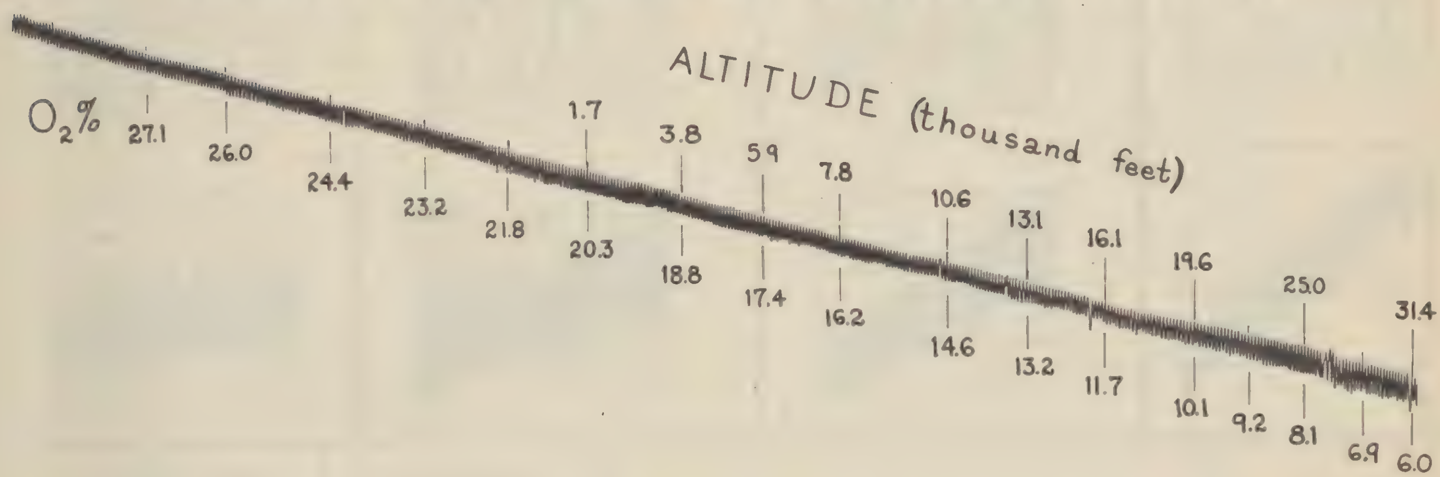
(7) III-12c November 1944, H.F.Helmholz Jr.
Oxygen carrying capacity of the blood. Effect of pressure breathing.

(8) IV-2 July 1940, W.R.Lovelace.
Comparitive volumes of gases (saturated at 37°C) inside the body at various altitudes.

MAYO AERO MEDICAL UNIT

RESPIRATORY CURVES

DECREASING OXYGEN CONCENTRATION



INCREASING CARBON DIOXIDE CONCENTRATION

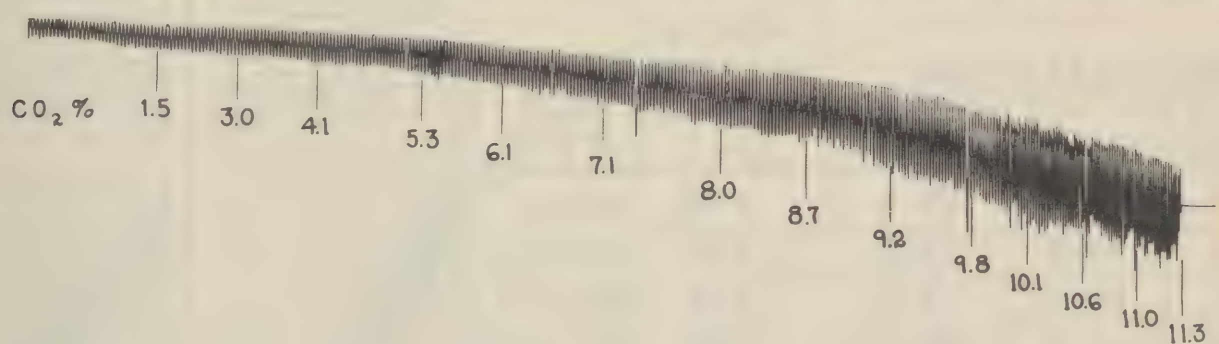
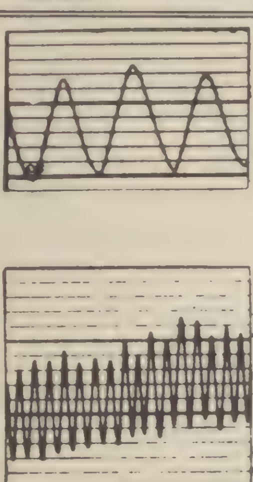


CHART NO. XI - 6 Subject H.O.B. 11-29-39

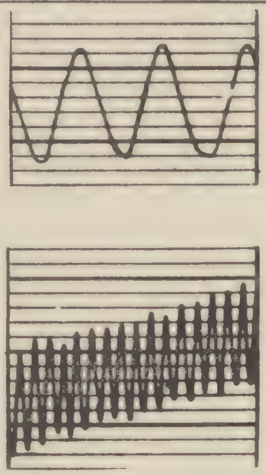
MAYO AERO MEDICAL UNIT

OXYGEN CONSUMPTION AND VENTILATION RATE PER MINUTE AT VARIOUS ALTITUDES WHILE BREATHING OXYGEN

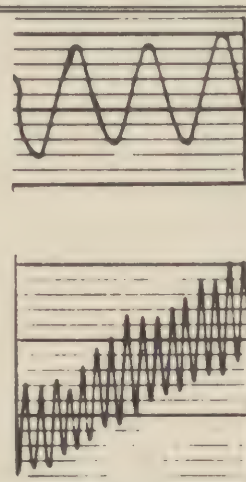
GROUND
BAR.: 733



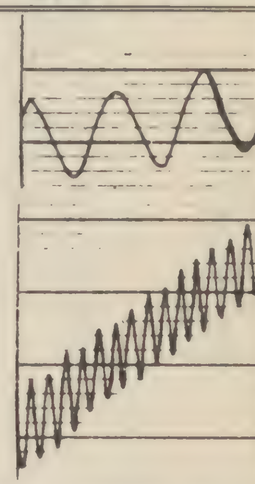
10,000 FT.
BAR.: 523



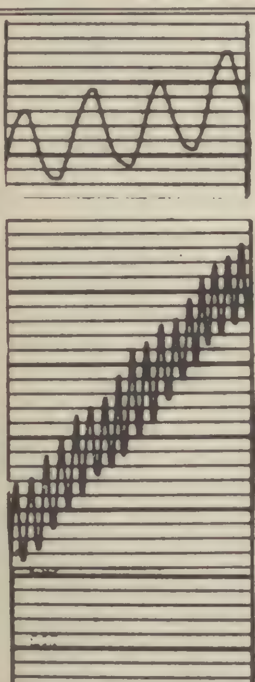
20,000 FT.
BAR.: 349



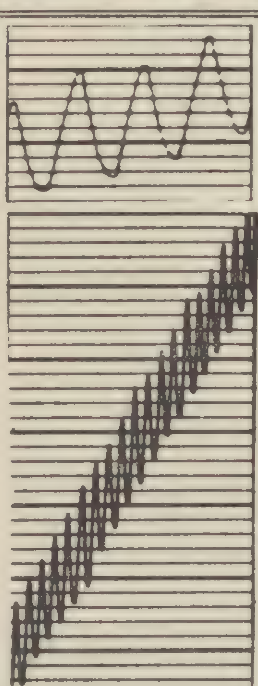
30,000 FT.
BAR.: 226



35,000 FT.
BAR.: 179



40,000 FT.
BAR.: 141



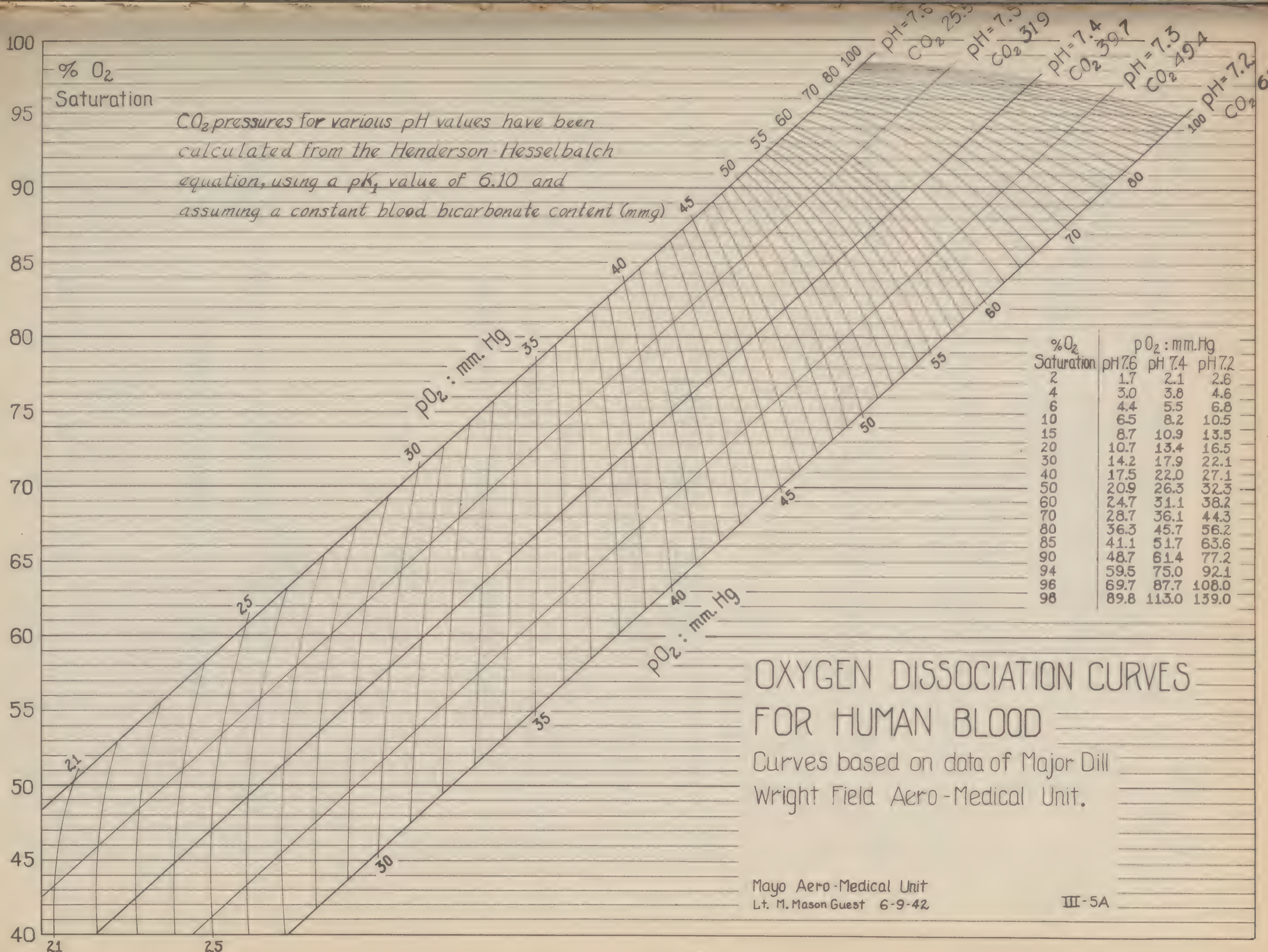
Sitting Rest

ALTITUDE IN FT.	O_2 CONSUMPTION S.T.P.D. c.c.	VENTILATION RATE S.T.P.D. Liters	VENTILATION RATE B-37°-D. Liters	VENTILATION RATE B-37°-S Liters
1,000	244	6.79	7.93	8.47
10,000	264	5.37	8.86	9.74
20,000	256	3.01	7.45	8.61
30,000	255	1.68	6.42	8.10
35,000	259	1.50	7.23	9.81
40,000	273	1.39	8.51	12.77

W M Boothby & O. O. Benson Jr
Jan 1940

Chart No. XIV - 1

Subject O.O.B. 1-29-40



OXYGEN DISSOCIATION CURVES FOR HUMAN BLOOD

Curves based on data of Major Dill Wright Field Aero-Medical Unit.

% O_2 Saturation	pO_2 : mm.Hg pH 7.6	pH 7.4	pH 7.2
2	1.7	2.1	2.6
4	3.0	3.8	4.6
6	4.4	5.5	6.8
10	6.5	8.2	10.5
15	8.7	10.9	13.5
20	10.7	13.4	16.5
30	14.2	17.9	22.1
40	17.5	22.0	27.1
50	20.9	26.3	32.3
60	24.7	31.1	38.2
70	28.7	36.1	44.3
80	36.3	45.7	56.2
85	41.1	51.7	63.6
90	48.7	61.4	77.2
94	59.5	75.0	92.1
96	69.7	87.7	108.0
98	89.8	113.0	139.0

Mayo Aero-Medical Unit
Lt. M. Mason Guest 6-9-42

III-5A

INCREASED CIRCULATION RATE WITH ANOXIA

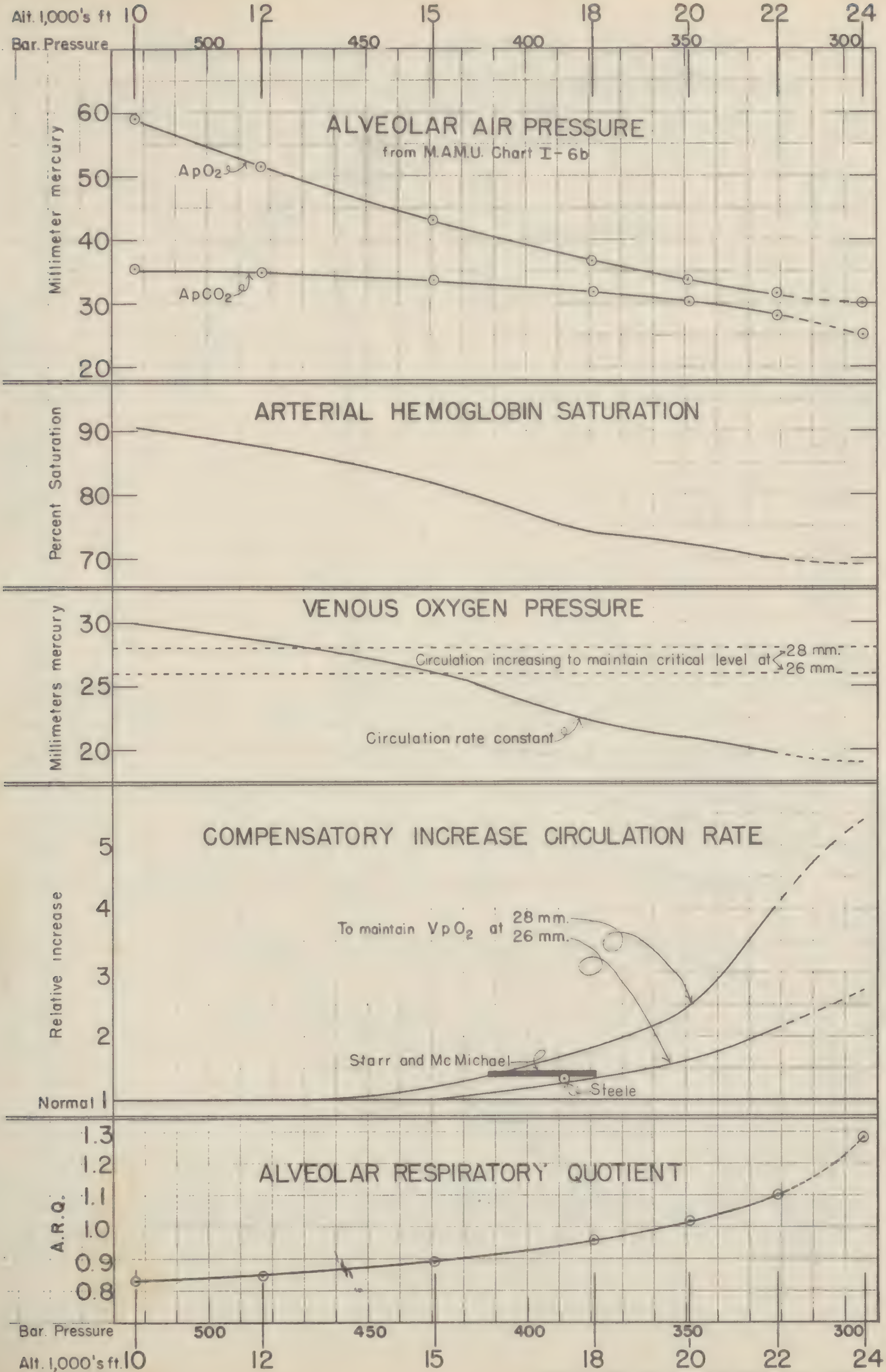
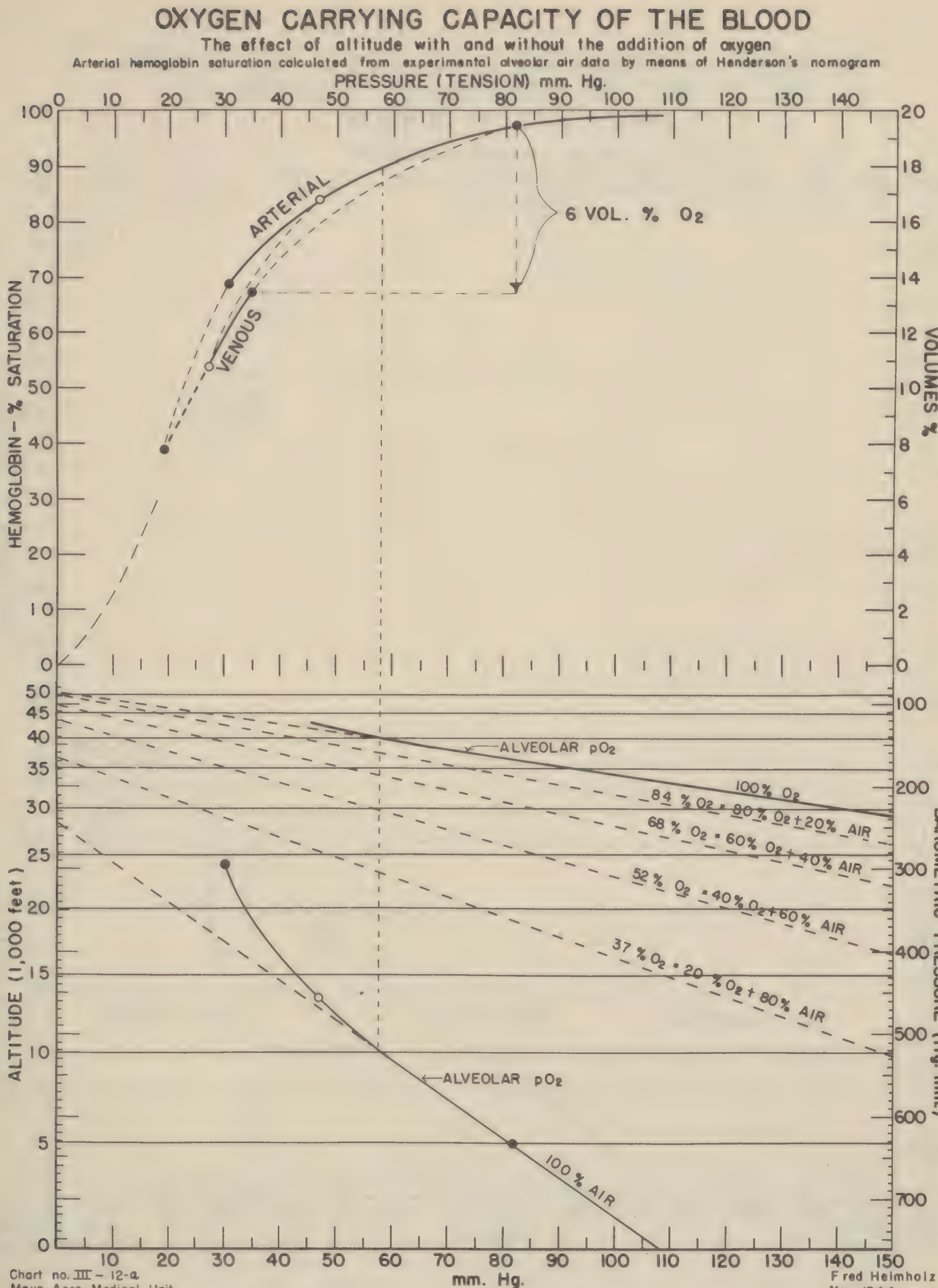


Chart IX-7

Helmholz, Bateman and Boothby Aug. 1944


OXYGEN CARRYING CAPACITY OF THE BLOOD
The effect of altitude with and without the addition of oxygen
Arterial hemoglobin saturation calculated from experimental alveolar air data by means of Henderson's nomogram
PRESSURE (TENSION) mm. Hg.
HEMOGLOBIN - % SATURATION
VOLUMES %
ARTERIAL
VENOUS
6 VOL. % O2
ALTITUDE (1,000 feet)
BAROMETRIC PRESSURE (Hg. mm.)
ALVEOLAR pO2
100% O2
84 % O2 = 80 % O2 + 20% AIR
68 % O2 = 60% O2 + 40% AIR
52 % O2 = 40 % O2 + 60 % AIR
37 % O2 = 20 % O2 + 80 % AIR
ALVEOLAR pO2
100 % AIR
mm. Hg.
Chart no. III - 12-a
Mayo Aero Medical Unit
Fred Helmholz
Nov. 1944

EFFECT OF DECREASING BAROMETRIC PRESSURE ON OXYGEN TRANSPORT BY THE BLOOD

INCREASE IN CIRCULATION

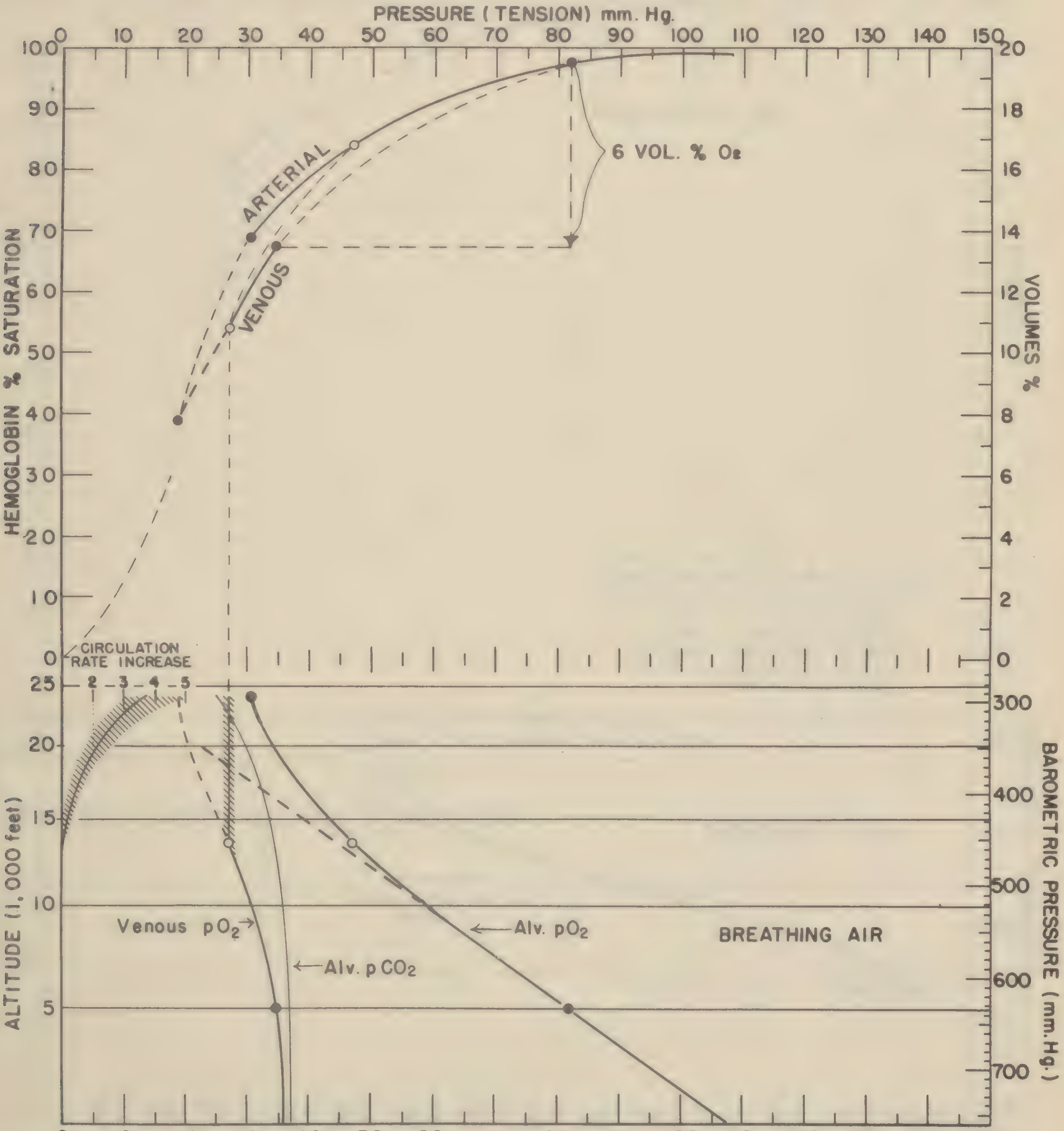


Chart no. III - 12-b
Mayo Aero Medical Unit

Fred Helmholz
Nov. 1944.

OXYGEN CARRYING CAPACITY OF THE BLOOD

EFFECT OF PRESSURE BREATHING

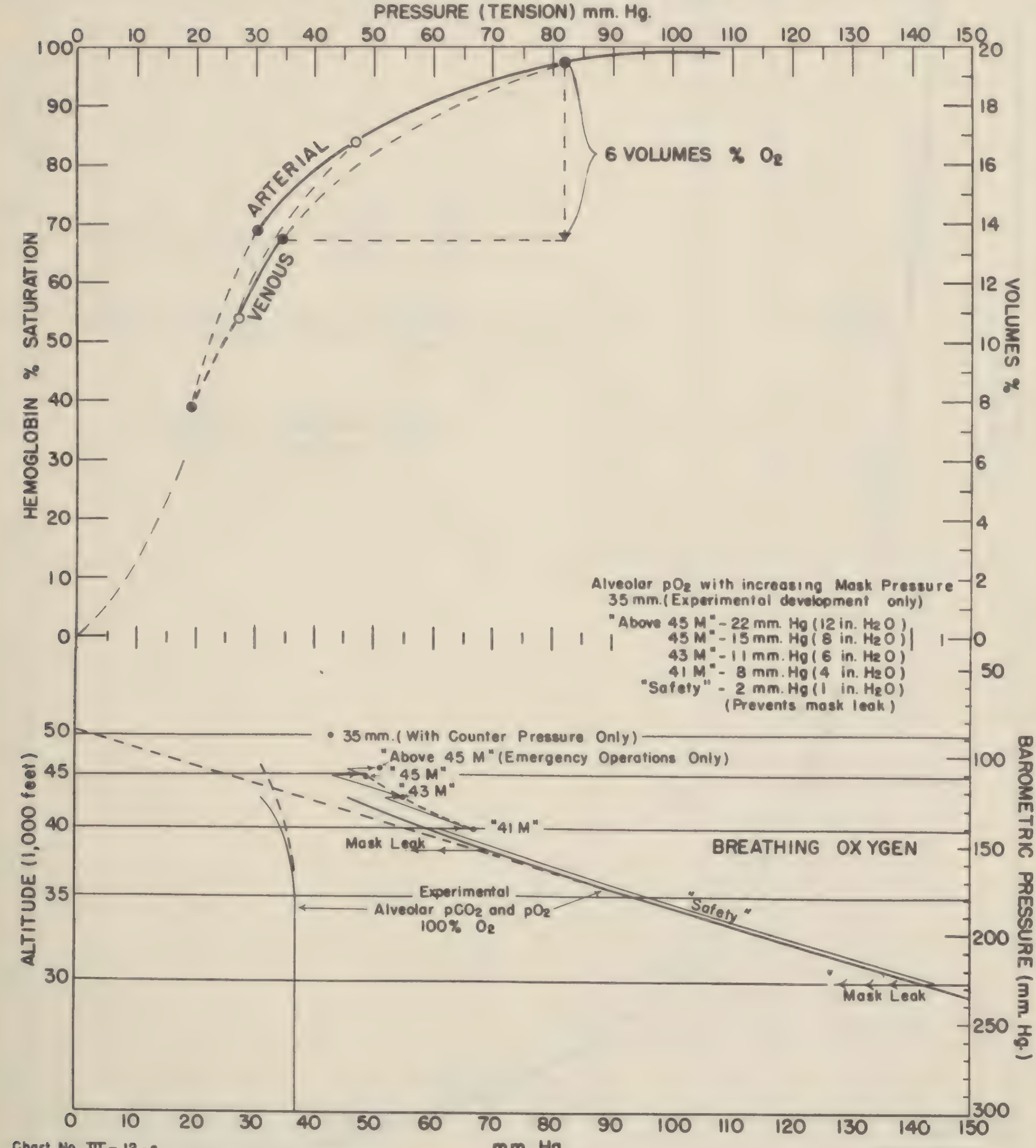
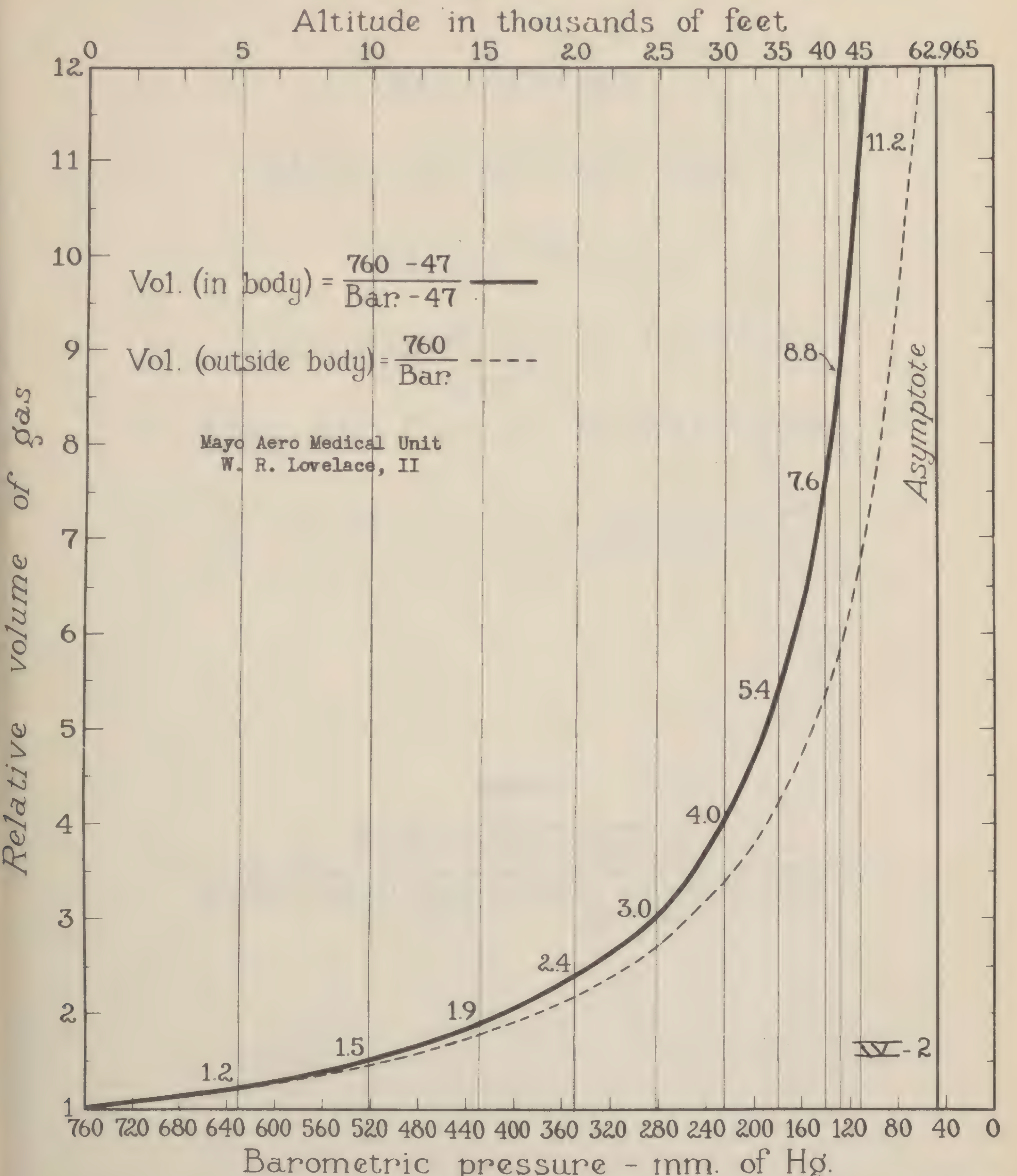


Chart No. III - 12 - c
Mayo Aero Medical Unit

Fred Helmholz
Nov. 1944

Comparative volumes of gases (saturated at 37°C*) inside the body at various altitudes



W-8008, AF

*Pressure of aqueous vapor at 37°C is 47 mm. of mercury

8

July 1940

Bibliography

MAYO AERO MEDICAL UNIT

Special Reports
to
National Research Council
and to
Army Air Forces, Wright Field

I. High Altitude Laboratory
II. Acceleration Laboratory

<u>Appendix</u>

For the convenience of readers
the bibliography of papers previously published on
Anoxia and Oxygen in Aviation Medicine and in Clinical Medicine
by various members of the Mayo Clinic and Mayo Foundation
are presented in an Appendix.

MAYO AERO MEDICAL UNIT

HIGH ALTITUDE LABORATORY

Bibliography

A = Oxygen and Anoxia

B = Decompression Sickness

C = Pressure Breathing

D = Oxygen Equipment

E = Miscellaneous

A. OXYGEN AND ANOXIA

A-1 Oxygen and air pressure at various altitudes as they influence the efficient functioning of the aviator. Part I, Effect of water vapor. "Tracheal air" $[(B-47)PO_2]$ basis for comparing altitudes when breathing air, oxygen or mixtures using nitrogen to simulate altitude. Part II, The role played by combustion or respiratory quotient, hyperventilation and diffusion of gases in the final gaseous equilibrium in the pulmonary alveoli resulting in alveolar ratio.
By Walter M. Boothby.
Aug. 1942, CMR Special Report No. 5 (full text obtainable on request)
Oct. 1944, Abstract: CAM Report No. 340.

A-2 Indoctrination of 21 crews of 307th Bombardment Group.
By Walter M. Boothby.
Oct. 1942, AAF-CMR Report: Series A, No. 2.

A-3 Indoctrination of 21 crews of 307th Bombardment Group (abstract).
By Walter M. Boothby.
Dec. 1942, CMR-OSRD Progress Report No. 6.

A-4 Comparison of alveolar oxygen pressures, oximeter readings and percentage saturation of hemoglobin. Normal arterial saturation approximately 97 per cent.
By Walter M. Boothby and F. J. Robinson.
Apr. 1943, NRC (Com. Oxygen & Anoxia) Report No. 2.

A-5 Comparison of alveolar oxygen pressures, oximeter readings and percentage saturation of hemoglobin.
By Walter M. Boothby and F. J. Robinson.
June 1943, CAM Report No. 163.
Above replotted and combined with data from Naval Medical Research Institute, Bethesda, Maryland.
By Walter M. Boothby.
Aug. 1945, CMR-OSRD Progress Report No. 16.

A-6 Discussion of alveolar air data (sea level versus 5000 foot standard) by Boothby, Helmholz and Robinson.
By Walter M. Boothby.
July 1943, CMR-OSRD Progress Report No. 7.

A-7 "Tracheal" versus "alveolar" air: A review of the methods of selecting certain physiological data bearing on the design of oxygen supply system for aviators.
By J. B. Bateman and Walter M. Boothby.
Dec. 1943, CAM Report No. 222.

A-8 Comparison of alveolar air data on men and women at various altitudes. Chart I-6c with tabulated data.
By Walter M. Boothby.
Apr. 1944, CMR-OSRD Progress Report No. 9.

A-9 Tracheal oxygen pressure $[(B-47)fO_2]$. Best point of reference for comparison of altitudes.
By Walter M. Boothby.
Jan. 1944, CMR-OSRD Progress Report No. 8.

A-10 Comparison between low altitudes breathing air and high altitudes breathing oxygen on both the tracheal and alveolar air basis: 3 charts No. I-6d-b, I-6d-c and I-6d-d. These charts are obtainable in large size for use in class and pressure chamber instruction.
By Walter M. Boothby.
June 1944, CMR-OSRD Progress Report No. 10.

A-11 Alveolar respiratory quotients: an experimental study of the difference between true and alveolar respiratory quotients, with a discussion of the assumptions involved in the calculation of alveolar respiratory quotients and a brief review of experimental evidence relating to these assumptions.
By J. B. Bateman and Walter M. Boothby.
June 1944, CAM Report No. 341.

A-12 Comments on "A Study of Hyperventilation as a Means of Gaining Altitude and Voluntary Pressure Breathing" by L.E. Chadwick, A.B. Otis, H. Rahn, M.A. Epstein and W.O. Fenn. CAM Report No. 302, May 22, 1944, made at the request of Chief, Aero Medical Laboratory, Engineering Division, Wright Field, Ohio.
By J. B. Bateman
July 1944, AAF-CMR Report: Series A, No. 8 (Wright Field).

A-13 The effects of altitude anoxia on the respiratory processes. "Tracheal" and "alveolar" reference points in regard to comparable altitudes; steady and semi-steady states.
By H. F. Helmholz, Jr., J. B. Bateman and Walter M. Boothby.
Aug. 1944, CAM Report No. 360.

A-14 The reduction of alveolar carbon dioxide pressure during pressure breathing and its relation to hyperventilation, together with a new method of representing the effects of hyperventilation.
By J. B. Bateman and Walter M. Boothby.
Sept. 1944, CAM Report No. 381.

A-15 To study the effect of acclimatization of individuals to 6,200 feet altitude upon the alveolar air. Joint study of Wright Field and Mayo Aero Medical Unit made at Peterson Field, Colorado Springs.
By Capt. J. W. Wilson (and Walter M. Boothby).
Sept. 1944, AAF-CMR Serial No. Eng. 49-696-42 F.

A-16 Sea level alveolar pCO_2 and pO_2 carried out at San Diego in cooperation with the High Altitude Laboratory of Consolidated Vultee Aircraft Corporation.
By H. F. Helmholz, Jr.
June 1944, Progress Report No. 10.

A-17 Alveolar respiratory quotients: an experimental study of differences between true expired air and alveolar respiratory quotients.
By J. B. Bateman and Walter M. Boothby.
Oct. 1944, CMR-OSRD Progress Report No. 11.

A-18 Effects of altitude anoxia on respiratory processes by Helmholz, Bateman and Boothby. Preliminary notes.
By Walter M. Boothby.
Oct. 1944, CMR-OSRD Progress Report No. 11.

A-19 Comments on "The Calculation of Equivalent Altitude" by J.S. Gray, prepared at request of Chief, Aero Medical Laboratory, Engineering Division, Wright Field.
By J. B. Bateman.
Oct. 1944, AAF-CMR Report: Series A, No. 9 (Wright Field).

A-20 Study of residual air and lung emptying time.
By H. F. Helmholz, Jr. and J.B. Bateman.
Oct. 1945, CMR-OSRD Progress Report No. 17.

A-21 Unequal pulmonary ventilation, residual air and "average" alveolar air.
By J. B. Bateman.
Feb. 1945, CMR-OSRD Progress Report No. 13.

A-22 Unequal pulmonary ventilation, residual air stressing errors due to nitrogen elimination.
By J. B. Bateman.
July 1945, CMR-OSRD Progress Report No. 15.

A-23 Effect on ceiling attainable and on the alveolar air data of 3 individuals originally acclimatized to low levels (1,000 feet, Rochester, Minnesota) on going to the higher levels around Colorado Springs (6,200 feet).
By Walter M. Boothby, Mayo Aero Medical Unit and J. W. Wilson, Wright Field.
Aug. 1944, AAF-CMR Report: Series A, No. 8a.

A-24 Dark adaptation.
I. Apparatus and methods.
II. Effects of anoxia.
III. Effects of fasting and of high carbohydrate meals on the courses and threshold values of dark adaptation obtained at ground levels, using air and oxygen.
By C. Sheard, J. W. Brown and K. G. Wilson.
June 1942, AAF-CMR Report: Series B, No. 1.

B. DECOMPRESSION SICKNESS.

B-1 Accumulated nitrogen elimination.
By Walter M. Boothby, W. Randolph Lovelace and Otis O. Benson.
AAF-CMR Report, Wright Field.
Abstracted in Physiology of Flight, 1940-42, page 27, Fig. 15.

B-2 Demonstrating air bubbles in wrist joint by roentgenogram while at 35,000 feet.
By Walter M. Boothby, Otis O. Benson and Harold A. Smedal.
AAF-CMR Report by Wright Field.
Reproduced in Physiology of Flight, 1940-42, page 26, Fig. 14a and 14 b.

B-3 Decompression symptoms developing during indoctrination of 21 crews of 307th Bombardment Group.
By Walter M. Boothby.
Oct. 1942, AAF-CMR Report: Series A, No. 2.

B-4 Nitrogen elimination illustrated by three charts: Chart VII-1, accumulated nitrogen eliminated at rest and at work; Chart VII-2, comparison (1) gaseous nitrogen eliminated while breathing oxygen and (2) venous blood nitrogen content; Chart VII-3, comparison of nitrogen elimination by heavy and light subjects.
By Walter M. Boothby and C. F. Code.
Sept. 1942, CMR-OSRD Progress Report No. 5.
Also detailed report by Code to Subcommittee on Decompression icknoss.

B-5 Aero-embolism. Preliminary report on the protective effect of prolonged inhalation of air oxygen mixture by Bateman.
By Walter M. Boothby.
Apr. 1944, CMR-OSRD Progress Report No. 9.

B-6 Aero-embolism. Further data on protective effect prolonged inhalation air-oxygen mixtures by Bateman.
By Walter M. Boothby.
June 1944, CMR-OSRD Progress Report No. 10.

B-7 Susceptibility to decompression sickness: the effects of prolonged inhalation of certain nitrogen-oxygen mixtures compared with those of exposure to pure oxygen.
By J. B. Bateman.
Sept. 1944, CAM Report No. 364.

B-8 To study the effect of acclimatization of individuals to 6,200 foot altitude upon alveolar air. (Joint study by Wright Field and Mayo Aero Medical Unit carried out at Peterson Field, Colorado Springs.)
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MAYO AERO MEDICAL UNIT

ACCELERATION LABORATORY

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